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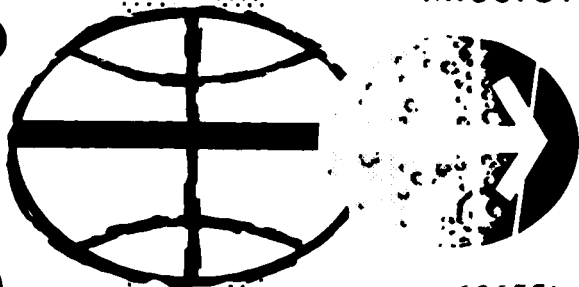# MSC INTERNAL NOTE NO. 68-FM-295

December 11, 1968

APOLLO 8

SEPARATION AND RECONTACT

ANALYSIS SUMMARY DOCUMENT
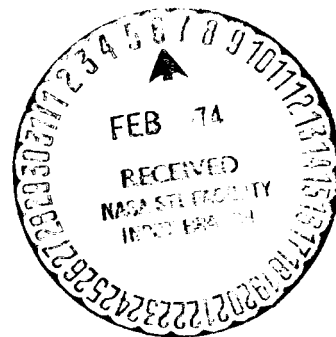
Flight Analysis Branch and TRW Systems Group

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

PROJECT APOLLO

APOLLO 8 SEPARATION AND RECONTACT ANALYSIS SUMMARY DOCUMENT

By Flight Studies Section
Flight Analysis Branch

December 11, 1968

MISSION PLANNING AND ANALYSIS DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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APOLLO 8 SEPARATION AND RECONTACT ANALYSIS

SUMMARY DOCUMENT

By Flight Studies Section

1.0 SUMMARY AND INTRODUCTION

This report is a summary of separation and recontact analyses for the Apollo 8 mission. The purpose of this study is to isolate the conditions that produce a recontact possibility and suggest procedures to alleviate the situation. In addition a summary of all separation and recontact analysis applicable to Apollo 8 is given in table I for use as a reference to specific study areas and to the possibility of recontact problems.

The text of this report begins with Section 3 which is a study from the recontact point of view of the nominal mission. The two time regions during the nominal mission when recontact situations could possibly arise (following CSM/S-IVB/SLA separation and after CM/SM separation) were studied in detail and presented no recontact problems.

Section 4 is concerned with separation and recontact analysis of abort conditions. It is divided into two major sections. In Section 4.1 recontact problems which might arise during the region from abort initiation to CM/SM separation are investigated. Several problem areas arise.

1. If the TVC/SCS is used to damp separation rates (assuming the abort was due to tumbling), there are crew performance conditions which could result in recontact. The results of Section 4.1.1 suggest bounds for these conditions which would eliminate recontact between the CSM and S-IVB.

2. If RCS/SCS is used to damp the separation rates (LV tumbling), no recontact occurs during the rate damping process; however, recontact can occur between the CSM and either the S-IVB or the SLA panels following the SPS burns of launch abort modes III and IV. While it would be presumptuous to mininize the severity of the problem identified herein, it must be noted that the utilization of a mode III abort is unlikely. The probable mode of operation is to perform a mode IV (COI).

3.   Aborts from EPO, TLI, and TLC present no recontact problems except in the region of aborts initiated during the CSM post-TLI evasive maneuver (Section 4.1.5).

In Section 4.2, possible recontact problems following CM/SM separation are investigated. The results indicate no recontact problems exist during entry.

Section 5 presents the results of separation and recontact analyses associated with a detectable impending S-IVB explosion in orbit, CSM/S-IVB separation failure, and the effects of interface forces on the CM/SM separation.

2.0 SYMBOLS

APS	S-IVB attitude propulsion system
BA	bank angle
CO	cutoff
COI	contingency orbit insertion
CM	command module
CR	cross range
CSM	command and service modules
EDS	emergency detection system
EPO	earth parking orbit
GETI	SPS abort burn initiate (mode III or IV)
g.e.t.	ground elapsed time
LET	launch escape tower
LH	local horizontal
LH2	liquid hydrogen
LO	lift-off
LOS	line-of-sight
LOX	liquid oxygen
LV	launch vehicle
NPV	nonpropulsive vent
PV	propulsive vent
RCS	reaction control system
RLP	predicted full-lift landing range from launch pad

SC	spacecraft
SCS	stabilization and control system
SLA	spacecraft LM adapter
SM	service module
SPS	service propulsion system
TB7	time referenced to S-IVB second cutoff
TB5	time referenced to S-IVB first cutoff
Tff	time of free-fall to entry interface
T&D	transposition and docking
TLC	translunar coast
TLI	translunar injection
TVC	thrust vector control

3.0 SEPARATION AND RECONTACT ANALYSIS OF

NOMINAL PROCEDURES

There are only two regions when recontact situations could possibly arise. The first is during the events following CSM/S-IVB/SLA separation and the second after CM/SM separation. The analyses of these regions indicate that no recontact problems exist.

3.1 Nominal CSM/S-IVB Separation and Subsequent Events
Up to S-IVB Liquid Oxygen Dump

Twenty-five minutes after the second nominal S-IVB cutoff, the CSM separates from the S-IVB. Separation is followed by a simulated transposition and docking (T&D), and then a maneuver is performed that places the spacecraft in a favorable position that avoids recontact problems and allows visual monitoring during the S-IVB liquid oxygen (LOX) dump. The results of this analysis as given in reference 1 are summarized as follows:

The planned radially outward maneuver is initiated 40 minutes after the second S-IVB cutoff (TB7 + 40 minutes) with the CSM +X-axis aligned with the radius vector and directed toward the earth. The CSM -X RCS thrust is used to achieve a separation ΔV of 1.5 fps, resulting in a separation range from the S-IVB of approximately 12 500 ft at LOX dump initiation (TB7 + 132 minutes). This range continually increases throughout the S-IVB LOX dump. The position of the sun relative to the CSM during this period for any launch day during December 1968 or January 1969 creates no interference with CSM visual monitoring of the S-IVB. The midcourse correction ΔV required to compensate for this evasive maneuver is within acceptable limits, approximately 3 fps (ref. 2). An outline of the post-TLI events (ref. 1) is given in table II.

A pictorial description of the significant events is given on figure 1. The relative motion between the CSM and the S-IVB throughout the period from evasive maneuver initiation through LOX dump is presented in figures 2 and 3.

3.2 Nominal Entry

This section analyzes the target $V_i - \gamma_i$ corridor at entry interface (400 000 ft) given in reference 3 which will be utilized should an abort occur during the TLI and TLC phases and for the nominal mission. This analysis evaluates using the IMU out-the-window alignment attitudes at

a T_{ff} of 17 minutes to establish the CM/SM separation attitudes at a T_{ff} of 15 minutes. It presents a CM/SM entry separation analysis encompassing the entire entry corridor.

At a T_{ff} of 17 minutes, the crew will be in a heads-down position and at the attitude predicted for the planned out-the-window IMU alignment check-out. After this sequence is performed, this alignment pitch attitude will be maintained inertially until a T_{ff} of 15 minutes occurs. During this 2 minutes of T_{ff} the SC will perform the 45° out-of-plane yaw maneuver to be in the appropriate SM jettison attitude at T_{ff} = 15 minutes.

The analysis presented herein supersedes reference 4 which gives minimum separation distances between the CM and SM for nominal, TLI, and TLC abort reentries. The data presented in the reference was reevaluated and found to contain erroneous information and should be disregarded.

Reference 3 presents the Apollo 8 reentry V_i and γ_i target line, undershoot boundary line, and the overshoot boundary line. Based on the reentry conditions for these lines, the trajectory state vectors at T_{ff} of 17 minutes and 15 minutes and the associated pitch attitudes (ξ) from the local horizontal (defined in fig. 4) were computed. The change in pitch attitude between the two times of free fall for all three entry lines is insignificant (3° maximum) in relation to the separation distance during entry between the CM and SM. Figure 5 presents the minimum relative separation distance versus separation pitch angle for the nominal entry case (V_i = 36 071 fps and γ_i = -6.26°). As can be seen from this figure, the largest change in minimum separation distance is approximately 100 ft for the entire spread of possible pitch angles.

Relative vertical separation distance and relative down-range separation distance computation were plotted for the nominal entry case. Figure 6 presents the path of the SM relative to the CM for bank angles of 0°, 55° S, 90° S, 180°, and 55° N. Figure 7 gives the cross-range displacement versus radial displacements for these bank angle trajectories. In all cases where the CM bank angle was south of the orbit plane, the cross range was sufficient to insure no possibilities of recontact. In the case where the CM banked north of the orbit plane, figure 7 indicates the relative separation is much less; however, no recontact problems are encountered.

Table XI provides the down-range, cross-range, and vertical distances as a function of the entry velocity (ref. 3) for the target, undershoot boundary, and overshoot boundary lines. This table presents the separation distance parameters for CM altitudes of 400 000 ft,

200 000 ft, and 100 000 ft, and is applicable to nominal, TLI abort, and TLC abort cases. In all instances the SM is jettisoned 45° out-of-plane north of the ground track with a conservative low separation ΔV of 3 fps and follows a ballistic trajectory. The SM weight used was 21 500 lb. CM bank angles of 0°, 55° S, and 55° N were used for the target line entries while a CM bank angle of 0° was used for the overshoot and undershoot entry line cases.

No recontacts were noted for the target, undershoot boundary, and boundary line entries. At entry interface (400 000 ft) the separation range for all cases was between 2400 ft and 2800 ft. The worst cases encountered in the atmosphere were at an altitude of 200 000 ft for the undershoot boundary entries. The smallest separation range at 200 000 ft was 1.9 n. mi. associated with the undershoot boundary line entry velocity of 27 500 fps. Although the SM should break up prior to an altitude of 100 000 ft, separation ranges were computed at this altitude for information purposes.

In conclusion, the change in pitch attitude from local horizontal between T_{ff} of 17 minutes and 15 minutes does not significantly affect the relative separation distance between the CM and SM during a nominal, TLI abort, or TLC abort entry. Using the entry procedures for banking the CM south for the nominal entry (V_i = 36 071 fps, γ_i = 6.26°) will produce sufficient cross-range distance to eliminate any possibility of recontact. Banking the CM north of the orbit plane during entry decreases the cross-range separation distance to less than 500 ft but the down-range separation distance is in excess of 2000 ft. No recontacts are encountered for the target, undershoot boundary, and overshoot boundary line entries.

4.0 SEPARATION AND RECONTACT ANALYSIS OF ABORT SITUATIONS

The analyses of these abort regions are considered in two separate phases: (1) the phase from abort initiation to CM/SM separation, and (2) the CM/SM separation phase.

4.1 Analysis of the Phase from Abort Initiation to CM/SM Separation

This section analyzes launch phase aborts, EPO, TLI, and TLC aborts.[a]

4.1.1 <u>Launch phase aborts</u>.- Beginning with Apollo 8, all CSM/LV separation sequences employ SLA panel jettison. The panels are deployed by a thruster mechanism providing an initial rotational rate. After rotating 45° from the S-IVB +X-axis, the panels disengage from their hinges, and spring thrusters (two per panel) provide an initial separation ΔV. This spring thruster ΔV combined with the panel rotation produces resultant velocities of 10.7 ± 1.0 fps at 100° ± 5° from the +X-axis of the S-IVB.

The analysis consists of a parametric study of the motion between the CSM and the LV and jettisoned SLA panels with LV tumble rates as the variable. For this study, the abort is assumed to be precipitated by a J-2 hardover failure, which represents worst-case conditions. The resultant angular acceleration is the greatest when the moments and products of inertia are the least, and for Apollo 8 this occurs near insertion. Therefore, mass properties for a light S-IVB rather than a heavier one are used in all cases, thus yielding a wider range of the variables to be considered. These mass properties for the CSM and S-IVB are given in table III.

Recontact between the CSM and LV or SLA panels is defined to occur if the CSM intercepts any one of five spheres with radii of 100 ft and origins at the centers of gravity of the S-IVB and the four SLA panels.

Two subsystems containing several operational control modes are available for damping the resultant tumble rates during launch phase aborts. The thrust vector control subsystem (TVC) utilizes the SPS engine when tumble rates are excessive,[b] while the reaction control subsystem (RCS) can be used to damp out low tumble rates. Both systems, which are under the control of the stabilization and control subsystem (SCS) have basic deficiencies. The inherent disadvantage of the RCS/SCS is that it requires a longer damping time than the TVC/SCS. This may create possible gimbal lock conditions when moderate or high yaw tumble

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[a]An abort can result in COI or an alternate mission.
[b]There is no well-defined area of usage.

rates are encountered. A longer rate damping time also introduces the possibility of performing CM/SM separation before rates are completely damped, especially in time-critical abort regions (early mode II). The inherent disadvantage in using the TVC/SCS is the lack of guidance control of the CSM during the time of SPS rate damping. This inability to control the direction of travel could result in rapid closure between the CSM and the S-IVB or SLA panels. A more complete discussion of the control systems used for rate damping is available in reference 18.

Several critical situations arise from tumbling aborts initiated during the launch phase (abort modes III and IV), in which the CSM can recontact the launch vehilce (either the S-II + S-IVB or the S-IVB) or recontact the jettisoned SLA panels. In the regions where definite recontact possibilities exist, crew reaction time in performing abort procedures determines whether or not the recontact can be averted. For the purposes of this study, the first crew reaction time (CRT1) is defined as time from emergency detection system (EDS) activation (vehicle tumble rates reach 10 deg/sec) to time of crew abort command initiation. The second crew reaction time (CRT2) is time from SCS enablement (approximately 0.8 seconds after CSM/LV separation) to time of crew rate damping initiation.

The launch phase abort recontact analysis is contained in reference 5. These abort modes are defined in reference 6.

4.1.1.1 Mode II: The mode II abort region covers a portion of the S-II burn and the early part of the S-IVB burn. The sequence of events for mode II with the respective times is given in table IV.

The boost portion of mode II is analyzed by investigating the effectiveness of the TVC/SCS and RCS/SCS to perform rate damping without causing recontact. Since the LV configuration throughout mode II (either S-II + S-IVB or S-IVB) is heavier than the one considered in the simulation, the body rate buildup is decreased for a specified value of CRT1 and the recontact line presented in figure 8 is necessarily conservative when applied to mode II aborts. Although the results of the study indicate recontact between the CSM and the LV when TVC/SCS rate damping is used, values of CRT2 > 23 seconds are necessary to precipitate this recontact since typical values of CRT1 are 1 second or less (fig. 8). Consideration of the mode II abort sequence indicates that a CRT2 > 23 seconds is extremely remote.

No recontact problem occurs when RCS/SCS rate damping is used, but the problems of gimbal lock and tumbling at CM/SM separation could result. These problems are less critical for a tumbling abort separation from the S-II + S-IVB than for a S-IVB separation, since rates will be lower for the heavier configuration.

Reference 7 investigates the motion of the SLA panels relative to the S-II + S-IVB. This referenced study defines recontact possibilities between the LV and the SLA panels, and states that a possible result is a LV explosion which could damage the SPS engine bell, but not the spacecraft body. These recontact regions exist during the first 70 seconds after LET jettison and during the last 20 seconds of S-II flight.

4.1.1.2 Mode III: The mode III abort procedures are required for contingencies beyond mode II ($Rlp > 3200$ n. mi.) when a safe orbit cannot be achieved or when SC systems malfunctions dictate immediate landings. The first mode III requirement is unlikely because of the large COI region and the S-IVB cutoff conditions would have to be greatly dispersed from the nominal launch trajectory. The second is unlikely because if such a malfunction had occurred during launch, the abort would more probably be initiated before entering mode III, and failures occurring after entering mode II would be almost impossible to confirm in sufficient time to recommend a mode III abort. These type failures are undefined at present (ref. 8). However, should a condition arise which requires a mode III abort, separation and recontact analysis has been performed utilizing the mode III abort sequence given in table V.

Since mode III has an SPS retrograde burn 2 minutes 5 seconds after separation, two regions of recontact exist: (1) immediate recontact occurring at any time prior to the retrograde burn, and (2) eventual recontact occurring at any time after SPS retrograde burn initiation.

All conclusions drawn from the analysis and pertaining to separation and recontact for a mode II tumbling abort (Section 4.1.1.1) are also applicable to the immediate recontact region of mode III. The weight configuration used in the analysis again causes the results to be conservative when applied to this mode III region.

Eventual recontact (following retrograde burn initiation) with the jettisoned SLA panels can occur for RCS/SCS rate damping in mode III. The recontact region is presented in figure 9 for variable CRT1 and S-IVB hardover rates. It must be noted that these data represent the conditions near insertion and are considered the worst case for the launch phase. Earlier aborts would cause crew reaction times to become less critical.

Using the TVC/SCS to damp rates could also cause a recontact possibility if the CSM is ahead of the LV after body rates are damped, and the SPS retrograde (deorbit) burn is initiated. Caution should be exercised prior to SPS ignition by visually establishing the relative position of the S-IVB to the SC, if possible.

4.1.1.3 Mode IV: The mode IV abort procedure incorporates a posigrade SPS burn to establish a safe orbit condition defined as a perigee altitude > 75 n. mi. The mode IV abort region overlaps the mode II and III abort boundaries, and will be utilized as the prime operating mode whenever the capability exists to achieve a contingency orbit insertion (COI). The abort sequence of events for mode IV is given in table VI.

The results of the rate damping analysis for hardover failures as summarized in section 4.1.1.1 are also applicable to the mode IV abort region for both TVC/SCS and RCS/SCS rate damping control modes prior to COI maneuver initiation.

Eventual recontact is a possibility if the CSM is behind the S-IVB after the body rates have been damped, and the SPS posigrade ΔV burn (COI) is initiated. In the event a hardover failure occurs and after damping has been completed caution should be exercised prior to SPS ignition to attempt to visually establish the relative position of the S-IVB to the SC.

4.1.1.4 Conclusion: In the event of LV hardover rates, crew performance (CRT1 and CRT2) prior to and after separation determines if recontact between the SC and the LV or SLA panels is a problem. Recontact cannot be allieviated for all conditions that could prevail in modes II, III and IV by using the RCS or SPS to perform rate damping. However, based on the analysis performed herein and considering the hardover rate conditions that could prevail during the launch phase the TVC/SCS appears to be a better mode of operation if crew reaction times are comparable to the sequences of events as described herein for modes II, III, and IV. It should be stressed that the primary disadvantage of using RCS/SCS is the possibility of gimbal lock for yaw tumble rates, and the possibility of a tumbling CM/SM separation for high LV separation rates. It must be noted the analysis presented herein presents trends of potential recontact problems, and extreme care should be exercised when these modes of operation prevail.

4.1.2 Launch and orbital phase aborts, non-tumbling.- Analyses have been conducted to determine if recontact problems exist between the SC, LV, and the SLA panels during stable, non-tumbling launch phase and orbital aborts. The results indicate that recontact is possible during the early mode III abort region between the SC and the SLA panels, and between the SC and S-IVB for the orbital abort region where CSM/S-IVB separation occurs in a posigrade attitude with 10 instead of the recommended 21 seconds of initial +X translation.

4.1.2.1 CSM/SLA panels: Reference 9 presents the analysis of SLA panel jettison with respect to the CSM for a range of non-tumbling launch phase and orbital aborts. This analysis indicates an adequate separation occurs for all launch phase and orbital aborts except in the early phase of the mode III abort region. In this region, the in-plane retrograde SPS maneuver performed at 2 minutes 5 seconds after abort initiation could result in the SC flying near or between the jettisoned panels. There exist abort conditions in this region where recontact could occur.

4.1.2.2 CSM/S-IVB: Reference 10 presents the analysis to identify existing CSM/S-IVB recontact problem areas in the mode II, III, and IV abort regions. Abort sequences previously defined for each mode were simulated and no recontact areas were identified.

CSM/S-IVB separation for aborts initiated while in EPO were investigated by reference 11 employing an initial separation burn by the RCS +X thrusters of 10 seconds. This sequence produced recontact between the CSM and S-IVB for several abort situations. Recontact is eliminated for all orbital aborts from a stable S-IVB if the initial +X translation separation is increased from 10 to 21 seconds and the S-IVB/APS ullage is inhibited. This sequence is recommended to be used where manual takeover of S-IVB to reorient to retrograde attitude is not feasible. This sequence is given in table VII.

4.1.3 Separation procedures for aborts initiated during the second S-IVB burn (TLI) and the 90 minute TLC abort.- Should a critical subsystem failure occur during TLI and necessitate the shutdown of the S-IVB and the immediate return of the crew to earth, the fixed attitude abort would be performed 10 minutes after S-IVB shutdown and targeted to the contingency entry target line. The TLI abort horizon reference attitude is presented in figure 10.

If possible, however, the S-IVB will be allowed to burn to guidance cutoff, and if it is determined that an abort maneuver is still required, the ground and crew will begin preparations leading to an abort maneuver performed approximately 90 minutes after TLI cutoff. The 90 minute abort horizon reference attitude is presented in figure 11.

The analysis of this section considers the relative motion of the four jettisoned SLA panels. For identification and simplification the four SLA panels are referred to as panel 1, 2, 3 or 4 throughout this report. The pitched up (+Z) and down (-Z) panels are numbered 1 and 2, respectively [fig. 12(a)]. The yawed right (+Y) and yawed left (-Y) panels are membered 3 and 4, respectively [fig. 12(b)]. A front view of all four panels is presented in figure 12(c).

4.1.3.1 TLI aborts: In the event a TLI abort is required, the recommended sequence of events (table VIII) is to perform a CSM radially outward evasive maneuver (ΔV = 1.5 fps) 60 seconds after CSM/S-IVB separation. This maneuver will insure adequate separation displacement between the spacecraft, the S-IVB and the four SLA panels prior to and after abort burn initiation.

Relative motion for TLI aborts is presented in figures 13 through 16. An analysis was performed for executing the evasive maneuver radially inward and outward for a mid TLI abort (second S-IVB ignition + 142 seconds) and late TLI abort (second S-IVB cutoff). Results indicate that minimum separation clearances of 800 [fig. 13(a)] and 900 ft [fig. 14(a)] occur between the spacecraft and the S-IVB for the radially inward cases, whereas for the radially outward maneuver, adequate separation range is generated. Minimum displacements are 1900 ft [fig. 15(a)] for the mid-TLI abort and 1300 ft [fig. 16(a)] for the late-TLI abort.

Therefore, the radially outward evasive maneuver sequence of table VIII is recommended for TLI aborts.

4.1.3.2 TLC 90 minute aborts: In the event a TLC 90 minute abort is required, the recommended sequence of events (table IX) is to perform a CSM radially outward evasive maneuver 60 seconds after CSM/S-IVB separation. This maneuver will insure adequate separation displacement between the spacecraft, the S-IVB and the four SLA panels prior to and after abort burn initiation.

Relative motion for the 90 minute TLC abort is presented in figures 17 through 20. An analysis was performed by executing the evasive maneuver either radially inward or outward. Results indicate that a minimum separation clearance of 6800 ft [fig. 17(a)] occurs between the spacecraft and panel 1 for the radially inward maneuver. The SLA panel relative motion presented in this analysis is based on a jettison ΔV of 8 fps at an attitude (θ) of 100° from the S-IVB +X-axis. To determine the effect on the minimum displacement indicate above, dispersions in ΔV from 8 to 12 fps and jettison attitudes from 95° to 120° were considered. The results presented in figure 18 for the radially inward case indicate that increasing the panel jettison ΔV or attitude will also increase minimum ranges. Therefore, for minimum values of ΔV = 8 fps and θ = 95°, panel 1 may pass as close as 4500 ft during the SPS abort burn.

The same dispersions were also considered for the recommended radially outward evasive maneuver. The results presented in figure 20 indicates that increasing SLA panel jettison ΔV or attitude also increases separation ranges. Therefore, for minimal values panel 1 may pass as close as 13 500 ft for the radially outward evasive maneuver.

In the 90 minute TLC abort sequence SC separation occurs at the nominal transposition and docking (T&D) attitude. Since SLA panel jettison occurs at separation, and since the roll attitude of the S-IVB at T&D is 180°, two of the SLA panels (panels 1 and 2) are jettisoned in the orbit plane and two (panels 3 and 4) are jettisoned out-of-plane. When a T&D attitude of 120° to 130° from the local horizontal and a SLA panel jettison attitude of 95° ± 5° is considered,

panel two will be aligned approximately with and jettisoned in the direction of the V_i, whereas panel 1 will be jettisoned along V_i in a retrograde direction.

Since any TLC SPS abort ΔV is necessarily directed opposite to V_i, the problem of recontact with one of the SLA panels exists. A desirable way of avoiding this problem would be to roll the S-IVB 45° prior to CSM/S-IVB separation. This would result in all panels being jettisoned with sufficient out-of-plane displacement to eliminate any recontact problems for TLC aborts. This would also lessen considerably the possibility of panel recontact with the SC due to mid-course correction maneuvers.

4.1.4 TLC aborts initiated during station keeping.- In the Apollo 8 nominal mission a simulated T&D and station keeping will be performed from SC separation (TB7 + 25 minutes) until evasive maneuver initiation (TB7 + 40 minutes). Should a critical subsystem failure occur during this time period requiring an immediate abort, the radially inward evasive maneuver sequence of table X ($\Delta V = 1.5$ fps) is recommend prior to SPS ignition.

The radially inward maneuver will place the CSM in a favorable position for performing deorbit as indicated by figure 21. The data presented show the relative motions of the S-IVB and SLA panels 1 and 2 for a radially inward evasive maneuver initiated anytime during station keeping (TB7 + 25 to 40 minutes). Panels 3 and 4 (not shown) are jettisoned out of plane and do not present a problem. The direction of the SPS abort burn ΔV vector is noted at 6° from the radius vector. For abort burns initiated later than TB7 + 90 minutes, this alignment decreases to approximately 2° at TB7 + 4 hours (fig. 22).

Relative motion (fig. 21) indicates that panel 1 will begin passing below and between the spacecraft and the earth after approximately TB7 + 90 minutes, therefore , it would be desirable to initiate the SPS abort burn prior to this time.

Performing a radially outward evasive maneuver for aborts initiated during station keeping is undesirable as the S-IVB is positioned between the spacecraft and the earth.

4.1.5 Post station keeping TLC aborts.- Following station keeping, the CSM will initate a radially outward evasive maneuver (TB7 + 40 minutes) as discussed in section 3.1. At TB7 + 120 minutes the S-IVB will begin propulsive venting (LH_2) and at TB7 + 132 minutes will initiate a 5 minute liquid oxygen dump. Should a contingency situation arise during this period of time (TB7 + 40 to 137 minutes)

requiring an immediate abort, possible recontact problems exists. As indicated by figures 3 and 23 respectively, the S-IVB and panel 1 can be positioned below the CSM. The S-IVB and panel 1 minimum separation range generated during an SPS abort burn are presented in figure 24.

Based on these minimum separation ranges, it is recommended that an SPS abort burn not be initiated during the first 40 minutes following the evasive maneuver (TB7 + 40 to 90 minutes) and during the S-IVB venting and LOX dump periods (TB7 + 120 to 137 minutes).

For aborts performed later than TB7 + 90 minutes, the angle between the thrust vector and the radius vector of the CSM will decrease from 6° at 90 minutes to about 2° at TLI + 4 hours. The above data is based on an SPS abort burn alignment of 2° (fig. 22) and represents the worst case with respect to separation range. Increasing the alignment angle also increases minimum separation ranges.

4.2 Analysis of the Period from CM/SM Separation to Touchdown

4.2.1 Discussion.- This section presents the results of CM/SM separation and recontact studies during entry following launch phase aborts, aborts from EPO, and TLI and TLC aborts.

4.2.2 Launch phase.- Reference 8 defines the gound elapsed time region for initiation of a mode II abort and the sequence of events to be followed after the abort. During the mode II abort, there are two major factors which affect the separation distance between the CM and SM after CM/SM separation. The first is the attitude of the CSM at the time of separation and the second is the T_{ff} remaining from separation to entry interface.

The range of pitch attitudes from the local horizontal chosen (fig. 25 and 26) for this analysis were +90° to -5°. This range includes the possible launch vehicle attitudes at the time of abort (assuming the LV is not tumbling). Figure 26 presents the minimum relative separation distance as a function of pitch attitude for a late mode II abort (T_{ff} of 118 seconds to 400 000-ft altitude). The minimum relative separation range changes by approximately 650 ft between a pitch angle of +90° and -5°, however, the separation distance for all attitudes is

sufficient to eliminate recontact. A decrease in free-fall time would also decrease the separation distance, but it was found that no recontact occurred for the minimum free-fall time of 40 seconds to 400 000 ft.

Two analyses were performed using the minimum and maximum T_{ff} corresponding to the beginning and end of the mode II abort region. The T_{ff} to 400 000 ft for the beginning and end of the abort region was 40 seconds and 118 seconds, respectively. At separation the SM was jettisoned retrograde with a ΔV obtained by burning the RCS jets to fuel depletion. During entry, the SM was assumed to follow a ballistic path. The CM flew a full-lift trajectory to touchdown. A pitch angle at CM/SM separation of +4.1296° was used as a worst case pitch attitude.

Figure 27 gives the relative earth radial separation and relative downrange separation distances for the 40 second and 118 second time of free-fall trajectories. There is no recontact for either time of free fall; however, the separation distances are much less for the T_{ff} of 40 seconds. Since the separation distances between the CM and SM decrease as the time of free fall decreases, the CM/SM separation should be performed as soon as possible after abort initiation to increase the separation distances.

The mode III abort sequence is defined in reference 8. Since the minimum separation distance is determined by the time of free fall remaining and the CM/SM separation pitch attitude, the worst case mode III abort was analyzed. This case corresponds to the beginning of the mode III region with a separation attitude of -132° (fig. 28 defines pitch attitude for mode III aborts).

The CSM was yawed 45° out of plane for this analysis and the SM was jettisoned with a separation ΔV of 3 fps. A ballistic SM trajectory and a CM constant bank angle trajectory of 55° south from 0.2g were simulated to determine the relative motion during entry. The relative down range versus relative earth radial separation during entry for this worst case is presented in figure 29.

It should be noted that the SM was jettisoned 45° out of plane for this recontact evaluation. This is not planned for mode III aborts and studies are in progress to define the separation distances associated with the correct separation sequence. The preliminary analysis indicates that the separation distances for the in-plane separation are less than the out of plane, but do not present a recontact problem. This analysis will be published shortly.

4.2.3 <u>Earth parking orbit phase</u>.- CM/SM separation following earth parking orbit aborts occurs with the CSM in the pitch attitude describe in figure 4. In this study it was assumed that separation was made at a minimum time of free fall of 8 minutes. The separation pitch angle for this worst case is +162.14°. The CSM was yawed 45° out of plane and a separation ΔV of 3 fps was used to jettison the SM. The relative motion of the CM and SM was determined by assuming that the SM flies a ballistic trajectory and the CM flies a full-lift trajectory to 0.2g, followed by a constant bank angle trajectory to touchdown. Figure 30 gives the relative separation distances between the CM and SM for bank angle trajectories of 0°, 55° S, 90° S, 180°, and 55° N. Recontact problems were not encountered for any of these CM trajectories.

As in the case of the mode III evaluation, the SM was separated 45° out of plane. An analysis is in progress to determine the separation distances for an in-plane separation. The results of this analysis is forthcoming.
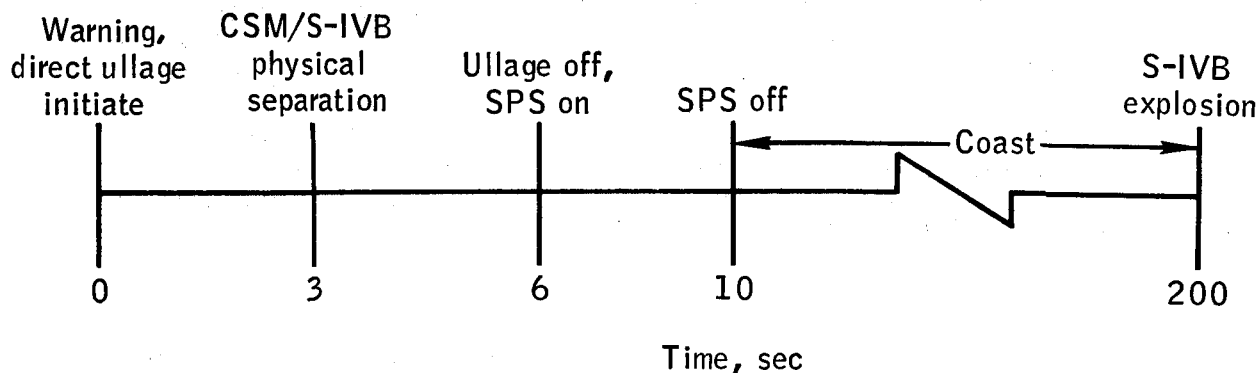
4.2.4 <u>TLI and TLC phases</u>.- There is no recontact between the CM and SM for TLI and TLC abort entries. The description of the analyses performed for these phases is considered in section 3.2.

5.0 SPECIAL ANALYSIS

5.1 Impending Detectable S-IVB Explosion in Orbit

A CSM maneuver which would produce an adequate separation distance
(7080 ft) between the CSM and S-IVB within the allowable warning time
(200 seconds) is investigated by reference 12. The recommended sequence
will produce the distance within 180 seconds after physical separation.
Assuming that 3 seconds of the warning time is consumed during the direct
ullage prior to separation, the crew has 17 seconds in which to initiate
the sequence after the warning signal is displayed.

The recommended sequence is as follows:

Warning, direct ullage initiate	CSM/S-IVB physical separation	Ullage off, SPS on	SPS off		S-IVB explosion

```
Warning,        CSM/S-IVB
direct ullage   physical      Ullage off,                              S-IVB
initiate        separation    SPS on      SPS off                      explosion
                                                    ←——Coast——→

0               3             6           10                           200

                                Time, sec
```

5.2 CM Separation from the S-IVB/SM

The possibility of separating the CM from the S-IVB/SM is analyzed
in reference 13 for mode II aborts. Mode II aborts were investigated
due to their time-critical nature, and the results will be applicable
to modes III and IV. Results show that the CM yaw engines produce a
sufficient separation distance from the S-IVB/SM to avoid close-in
recontact; however, long range recontact with S-IVB/SM breakup debris
cannot be completely ruled out.

5.3 Effects of Separation Interface Forces on Relative Motion
of the CM and SM Following Separation

Reference 14 presents the results of an analysis performed to determine
the effects of interface forces on the relative motion of the CM and

SM following separation. The list of variables considered for this study is as follows:

1. Vehicle pitch rate prior to separation.

2. Time interval after separation during which the SM roll jets are firing.

3. SM/RCS -X-jet failures.

4. Impulse due to ordnance gas pressure and release of stored elastic energy in CM/SM structure.

5. Impulse applied to CM caused by the umbilical guillotine.

6. Impulse applied to SM induced from the reaction to the umbilical guillotine impulse vector.

7. Impulse applied to SM caused by stop of swinging umbilical cable.

8. CM control system type and control system mode.

9. CM control system delay.

The results indicate that interface forces produced at the time of CM/SM separation only serve to reduce the possibility of recontact by driving the CM away from the SM. Of all the separate effects that were considered, the impulse caused by the ordinance gas pressure and release of stored energy was dominant. The minimum value of the impulse is sufficient to eliminate recontact.

TABLE I.- APOLLO 8 SEPARATION AND RECONTACT SUMMARY

Separations	Recontact problems	Discussion section	Reference	Comments
CM/SM				
Nominal entry abort entries from	No	3.2	—	
Mode II	No	4.2.2	—	Recontact cannot be completely ruled out if SM trims
Mode III	No	4.2.2	—	Recontact cannot be completely ruled out if SM trims
Mode IV	No	4.2.2	—	Recontact cannot be completely ruled out if SM trims
EPO	No	4.2.3	—	Recontact cannot be completely ruled out if SM trims
TLI	No	4.2.4	—	
TLC	No	4.2.4	—	
Interface force analysis	No	5.3	14	
CSM/SLA panels/S-IVB				
Nominal aborts	No	3.1	1	Nominal evasive maneuver sequence defined eliminates recontact problems
Tumbling				
Mode II	Yes	4.1.1.1	7	Recontact of SLA panel with LV during a mode II abort possible
Mode III	Yes	4.1.1.2	5	Recontact possible following retrograde SPS burn

TABLE I.- APOLLO 8 SEPARATION AND RECONTACT SUMMARY - Concluded

Separations	Recontact problems	Discussion section	Reference	Comments
Mode IV	Yes	4.1.1.3	5	Recontact possible following COI SPS burn
Non-tumbling				
Mode II	No	4.1.2	9, 10	Recontact possible with SLA panel during early mode II aborts
Mode III	Yes	4.1.2	9, 10	
Mode IV	No	4.1.2	9, 10	
EPO	No	4.1.2	9, 11	New sequence defined eliminates recontact problems
TLI	No	4.1.3.1	9, 11	New sequence defined eliminates recontact problems
TLC	Yes	4.1.5		Recontact possible for SPS abort burns initiated during the nominal post-TLI evasive maneuver
S-IVB impending explosion in orbit	No	5.1	12	
CM/SM+S-IVB	No	5.2	13	Recontact with lifting debris cannot be completely ruled out during entry

TABLE II.- POST-TLI SEQUENCE OF EVENTS

Time from TB7, sec	Event
0	Second S-IVB cutoff and attitude hold. Initiate LH2 and LOX nonpropulsive vents (NPV). Initiate LH2 continuous vent.
20	Command and hold local horizon.
150	LOX NPV turned off.
900	LH2 NPV turned off.
	LH2 PV turned off.
	Initiate maneuver to separation attitude. (Ref. 15)
	Freeze separation attitude inertially.
1500	Spacecraft (SC) separation (1.0 FPS ΔV) and SLA panel jettison.
1505	Coast to 50-ft separation distance.
1555	Null 0.5 fps separation rate.
1558	Pitch 180° (SC).
1594	Null 0.5 fps separation rate.
1610	Station keep; visual observation; photography.
2340	Orient to evasive maneuver attitude; CSM +X towards earth; aligned with radius vector.
2400	Initiate 1.5 fps radially outward evasive maneuver using -X RCS jets.
3600	LH2 NPV turned on.
4500	LH2 NPV turned off.
6540	Command to LOX dump attitude and hold with respect to the local horizontal; P = 216°, Y = 0°, R = 180° (ref. 16).
7200	LH2 propulsive vent (PV) turned on. (ΔV = 24.0 fps)

TABLE II.- POST-TLI SEQUENCE OF EVENTS - Concluded

Time from TB7, sec	Event
7920	Initiate LOX dump command on ($\Delta V = 75 \pm 16$ fps).
8220	S-IVB LOX dump command off
9000	S-IVB APS on ($\Delta V = 41$ fps).

TABLE III.- VEHICLE MASS PROPERTIES NEAR INSERTION (g.e.t. = 11 MINUTES) (REF. 17)

	Weight (lb)	Apollo Coordinate System Center of Gravity (in.)			Moment of Inertia About c.g. (slug ft²)			Product of Inertia About c.g. (slug ft²)		
		X	Y	Z	Ixx	Iyy	Izz	Ixy	Ixz	Iyz
S-IVB (with LTA-B and SLA)	212,977.5	117.2	0.8	-0.3	109,644	1,793,850	1,789,467	8,468.0	-795.0	-1,262.0
CSM	63,741.0	934.2	3.9	6.7	34,190	79,480	81,615	-1,852.6	-153.4	3,215.6

TABLE IV.- ABORT MODE II SEQUENCE OF EVENTS

Time, min:sec	Event
0:00	Abort initiate
	LV cutoff
	Direct ullage on
0:03	CSM/LV separation
0:03.8 (approximate)	SCS enabled
0:04 (nominal)	Four-jet uncontrolled "direct ullage" becomes +X translation under SCS control
0:04 + CRT2	CSM body rates are monitored
	a. If rates are not high, +X translation is maintained
	b. If rates are high, SPS rate damping is initiated (2 sec SPS burn minimum) and +X translation is terminated at SPS ignition +1.0 sec
0:24	Terminate +X translation if no SPS burn was required
	Execute CM/SM separation as soon as possible
1:40	Maneuver CM to entry attitude

TABLE V.- ABORT MODE III SEQUENCE OF EVENTS

Time, min:sec	Event
0:00	Abort initiate
	LV cutoff
	Direct ullage on
0:03	CSM/LV separation
0:03.8 (approximate)	SCS enabled
0:04 (nominal)	Four-jet uncontrolled "direct ullage" becomes +X translation under SCS control
0:04 + CRT2	CSM body rates are monitored
	a. If rates are not high, +X translation is maintained
	b. If rates are high, SPS rate damping is initiated (2 sec SPS burn minimum) and +X translation is terminated at SPS ignition +1.0 sec
0:24	Terminate +X translation if no SPS burn was required
	Maneuver CSM to horizon monitor retrograde attitude, heads up (fig. 28)
2:05	Initiate SPS burn
Time varies	Terminate SPS burn when target conditions satisfied

TABLE VI.- ABORT MODE IV SEQUENCE OF EVENTS

Time, min:sec	Event
0:00	Abort initiate
	LV cutoff
	Direct ullage on
0:03	CSM/LV separation
0:03.8 (approximate)	SCS enabled
0:04 (nominal)	Four-jet uncontrolled "direct ullage" becomes +X translation under SCS control
0:04 + CRT2	CSM body rates are monitored
	a. If rates are not high, +X translation is maintained
	b. If rates are high, SPS rate damping is initiated (2 sec SPS burn minimum) and +X translation is terminated at SPS ignition +1.0 sec
0:24	Terminate +X translation if no SPS burn was required
	Maneuver CSM to orbit insertion attitude (fig. 31)
2:05	Initiate SPS burn
Time varies	Terminate SPS burn on ΔV

TABLE VII.- ORBITAL ABORT SEQUENCE OF EVENTS[a]

Time, min:sec	Event
0:0	Abort initiate
	Direct ullage on
	Inhibit APS ullage
0:0	CSM/S-IVB separation
0:5	Begin +X translation
0:24	Terminate +X translation. Coast 30 seconds; orient to horizon monitor attitude (retrograde, heads up figure 28)
0:54	Begin +X translation
1:24	Terminate +X translation; orient to deorbit attitude (fig. 28)
20:00	SPS deorbit burn initiate
Variable	SPS off; target conditions satisfied

[a]This sequence is recommended to be used where manual take over of the S-IVB to reorient to retrograde attitude is not feasible.

TABLE VIII.- SEQUENCE OF EVENTS FOR TLI ABORTS

Time from TB7, min:sec	Event
00:00	Initiate abort S-IVB cutoff
	Initiate +X RCS ullage
00:03	CSM/S-IVB physical separation
	+X RCS translation on
00:13	+X RCS translation off align CSM +X-axis with radius vector, towards earth
01:00	Initiate 1.5 fps radially outward evasive maneuver
	-X RCS translation on
01:07.3	-X RCS translation off orient to SPS abort attitude (fig. 10)
10:00	Initiate SPS abort burn

TABLE IX.- SEQUENCE OF EVENTS FOR TLC 90 MINUTE ABORT

Time from TB7, min:sec	Event
00:00	S-IVB cutoff
25:00	Initiate abort CSM/S-IVB separation
	Initiate +X RCS translation
25:10	+X RCS translation off align CSM +X-axis with radius vector, towards earth
26:00	Initiate 1.5 fps radially outward evasive maneuver, -X RCS translation on
26:07.3	-X RCS translation off, orient to SPS abort attitude (fig. 11)
90:00	Initiate SPS abort burn

TABLE X.- SEQUENCE OF EVENTS FOR ABORTS INITIATED

DURING STATION KEEPING (TB7 + 25 to 40 MINUTES)

Time from abort initiation min:sec	Event
00:00	Initiate abort Align CSM +X-axis with radius vector, towards earth
00:60	End orientation Initiate 1.5 fps radially inward evasive maneuver +X RCS translation on
00:67.3	+X RCS translation off orient to SPS abort attitude (fig. 22)

TABLE XI.- CM AND SM ENTRY CORRIDOR RELATIVE SEPARATION DISTANCES[a]

(a) Target line entry, CM β = 0°

CM altitude = 400 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, ft
27 500	776	-1 604	1 674	2 445
31 500	209	-1 629	2 094	2 661
37 500	-238	-1 600	2 271	2 787

CM altitude = 200 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	121 272	8 458	-4 870	20.0
31 500	63 694	3 684	-3 202	10.5
37 500	36 565	1 328	-1 697	6.0

CM altitude = 100 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	600 992	203 937	-40 433	104.7
31 500	506 941	207 354	-44 562	90.4
37 500	383 862	190 320	-50 011	71.0

[a]X = Down-range position of the SM with respect to the CM.
    If the X quantity is positive, the SM is in front of
    the CM. A negative value indicates the SM is behind
    the CM.

Y = Cross-range position of the SM with respect to the CM.
    If the Y quantity is positive, the SM is south of the
    CM. A negative value indicates the SM is north of the
    CM.

Z = Vertical position of the SM with respect to the CM. If
    the Z quantity is positive, the SM is above the CM.
    A negative value indicates the SM is below the CM.

Range = $\sqrt{X^2 + Y^2 + Z^2}$

TABLE XI.- CM AND SM ENTRY CORRIDOR RELATIVE

SEPARATION DISTANCES[a] - Continued

(b) Target line entry, CM β = 55° S

CM altitude = 400 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, ft
27 500	776	-1 604	1 674	2 445
31 500	209	-1 629	2 094	2 661
37 500	-238	-1 600	2 271	2 787

CM altitude = 200 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	97 553	-105 294	-6 777	23.6
31 500	52 702	-49 987	-4 193	12.0
37 500	29 839	-28 516	-2 210	6.8

CM altitude = 100 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	-674 479	-814 258	-72 764	174.4
31 500	-896 084	-669 410	-85 289	184.6
37 500	-1 181 672	-402 119	-102 491	206.1

[a]X = Down-range position of the SM with respect to the CM.
If the X quantity is positive, the SM is in front of the CM. A negative value indicates the SM is behind the CM.

Y = Cross-range position of the SM with respect to the CM.
If the Y quantity is positive, the SM is south of the CM. A negative value indicates the SM is north of the CM.

Z = Vertical position of the SM with respect to the CM. If the Z quantity is positive, the SM is above the CM.
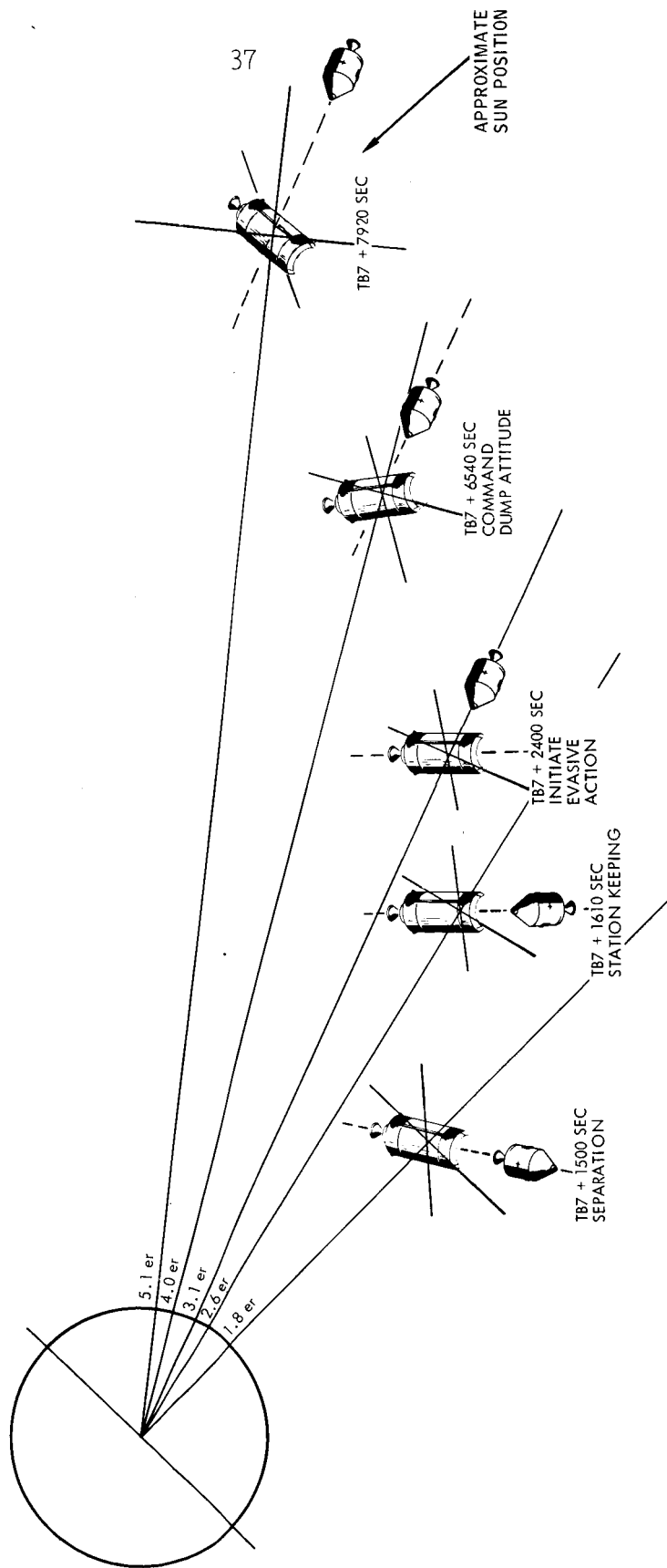A negative value indicates the SM is below the CM.

Range = $\sqrt{X^2 + Y^2 + Z^2}$

TABLE XI.- CM AND SM ENTRY CORRIDOR RELATIVE

SEPARATION DISTANCES[a] - Continued

(c) Target line entry, CM β = 55° N

CM altitude = 400 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, ft
27 500	776	-1 604	1 674	2 445
31 500	209	-1 629	2 094	2 661
37 500	-238	-1 600	2 271	2 787

CM altitude = 200 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	72 965	82 031	904	18.1
31 500	41 884	40 877	345	9.6
37 500	25 585	24 061	485	5.8

CM altitude = 100 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	-552 159	1 066 263	-45 139	197.8
31 500	-648 446	1 059 913	-48 174	204.6
37 500	-773 923	1 034 965	-53 430	212.9

[a]X = Down-range position of the SM with respect to the CM.
If the X quantity is positive, the SM is in front of
the CM. A negative value indicates the SM is behind
the CM.

Y = Cross-range position of the SM with respect to the CM.
If the Y quantity is positive, the SM is south of the
CM. A negative value indicates the SM is north of the
CM.

Z = Vertical position of the SM with respect to the CM. If
the Z quantity is positive, the SM is above the CM.
A negative value indicates the SM is below the CM.

Range $= \sqrt{X^2 + Y^2 + Z^2}$

TABLE XI.- CM AND SM ENTRY CORRIDOR RELATIVE

SEPARATION DISTANCES[a] - Continued

(d) Undershoot boundary entry, CM β = 0°

CM altitude = 400 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, ft
27 500	670	-1 626	1 786	2 507
31 500	215	-1 631	2 107	2 673
37 500	-267	-1 587	2 291	2 800

CM altitude = 200 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	11 452	-745	140	1.9
31 500	13 701	-525	144	2.3
37 500	17 566	-182	-176	2.9

CM altitude = 100 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	139 545	73 305	-43 049	26.9
31 500	150 386	89 059	-46 498	29.8
37 500	160 712	108 991	-51 462	33.1

[a]X = Down-range position of the SM with respect to the CM.
If the X quantity is positive, the SM is in front of
the CM. A negative value indicates the SM is behind
the CM.

Y = Cross-range position of the SM with respect to the CM.
If the Y quantity is positive, the SM is south of the
CM. A negative value indicates the SM is north of the
CM.

Z = Vertical position of the SM with respect to the CM. If
the Z quantity is positive, the SM is above the CM.
A negative value indicates the SM is below the CM.

Range = $\sqrt{X^2 + Y^2 + Z^2}$

TABLE XI.- CM AND SM ENTRY CORRIDOR RELATIVE

SEPARATION DISTANCES[a] - Concluded

(e) Overshoot boundary entry, CM β = 0°

CM altitude = 400 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, ft
27 500	905	-1 468	1 314	2 168
31 500	191	-1 628	2 097	2 662
37 500	-258	-1 602	2 270	2 791

CM altitude = 200 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	54 598	3 029	42 498	11.4
31 500	26 813	1 024	24 139	5.9
37 500	13 475	-136	14 495	3.3

CM altitude = 100 000 ft				
Entry velocity, fps	X, ft	Y, ft	Z, ft	Range, n. mi.
27 500	318 098	30 641	140 953	57.5
31 500	297 598	30 284	130 985	53.7
37 500	278 420	28 319	120 865	50.2

[a]X = Down-range position of the SM with respect to the CM.
If the X quantity is positive, the SM is in front of
the CM. A negative value indicates the SM is behind
the CM.

Y = Cross-range position of the SM with respect to the CM.
If the Y quantity is positive, the SM is south of the
CM. A negative value indicates the SM is north of the
CM.

Z = Vertical position of the SM with respect to the CM. If
the Z quantity is positive, the SM is above the CM.
A negative value indicates the SM is below the CM.

Range = $\sqrt{X^2 + Y^2 + Z^2}$

APPROXIMATE SUN POSITION

TB7 + 7920 SEC

TB7 + 6540 SEC COMMAND DUMP ATTITUDE

TB7 + 2400 SEC INITIATE EVASIVE ACTION

TB7 + 1610 SEC STATION KEEPING

TB7 + 1500 SEC SEPARATION

5.1 er
4.0 er
3.1 er
2.6 er
1.8 er

Figure 1.- Pictorial Description of CSM/S-IVB Events from Nominal Separation Until LOX Dump Command
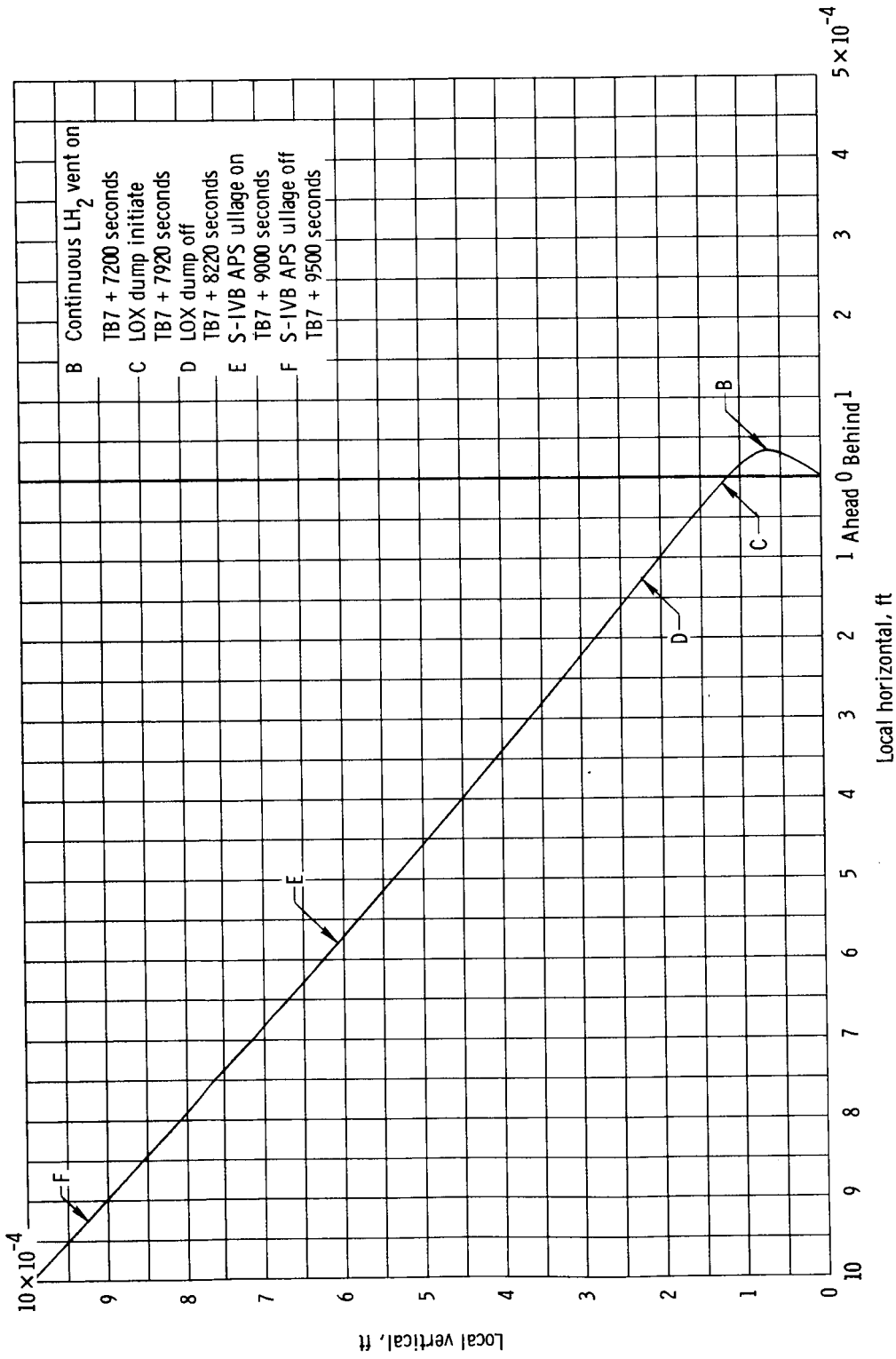
Figure 2. - Long-range motion of the CSM relative to the S-IVB subsequent to evasive maneuver initiation.
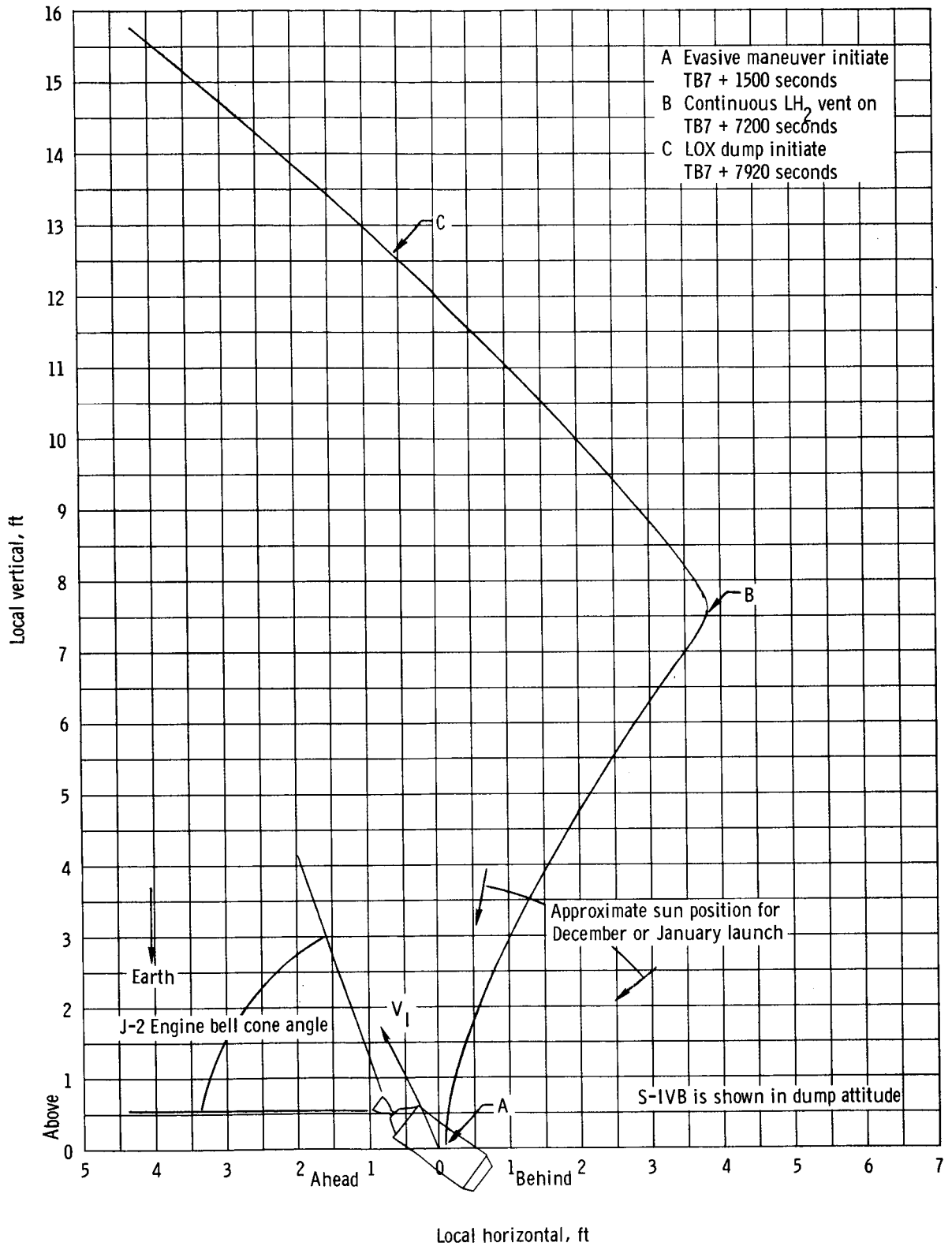
Figure 3. - Close-in motion of the CSM relative to the S-IVB subsequent to evasive maneuver initiation.
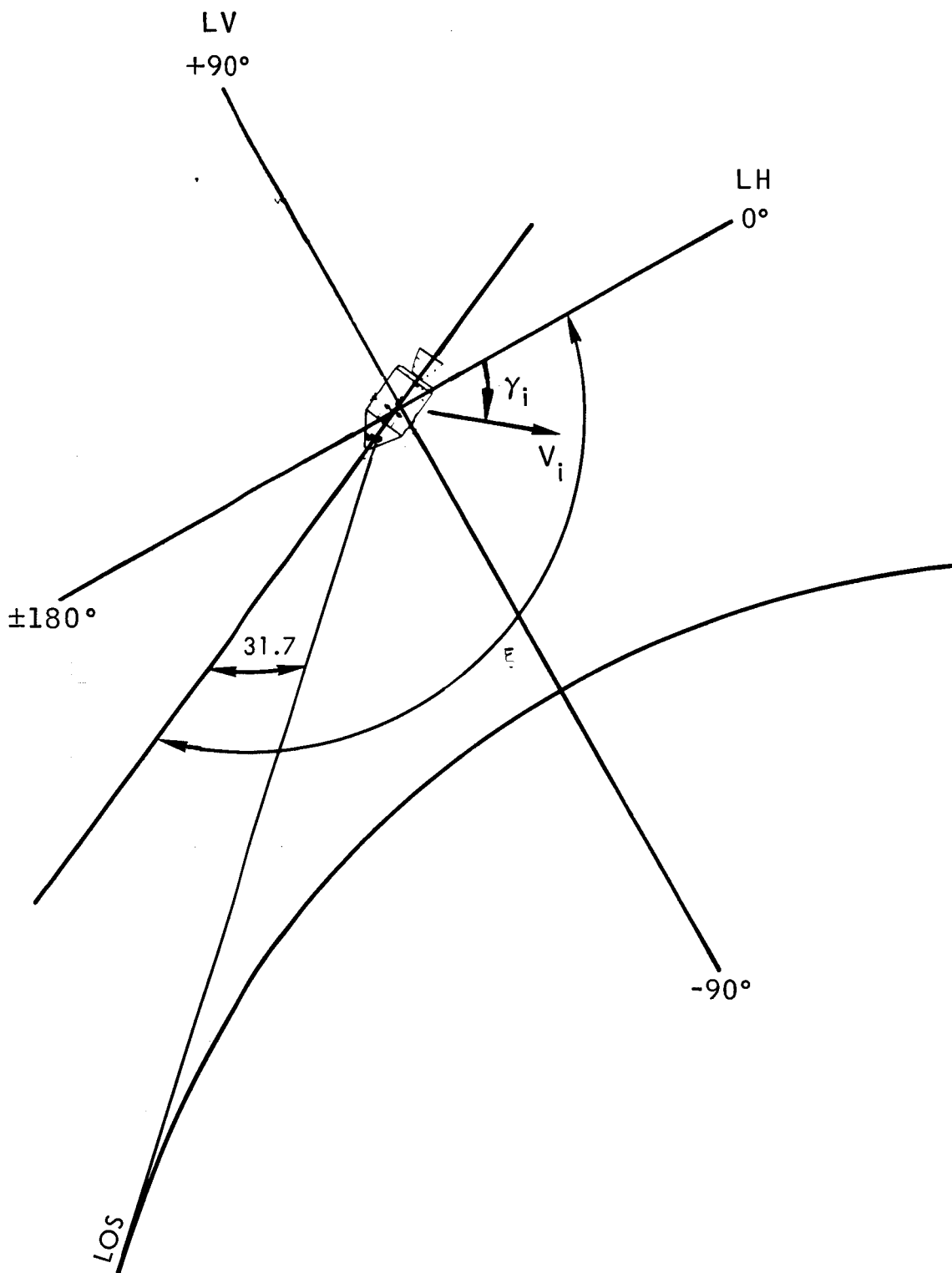
Figure 4.- CSM Heads Down Horizon Monitor Attitude
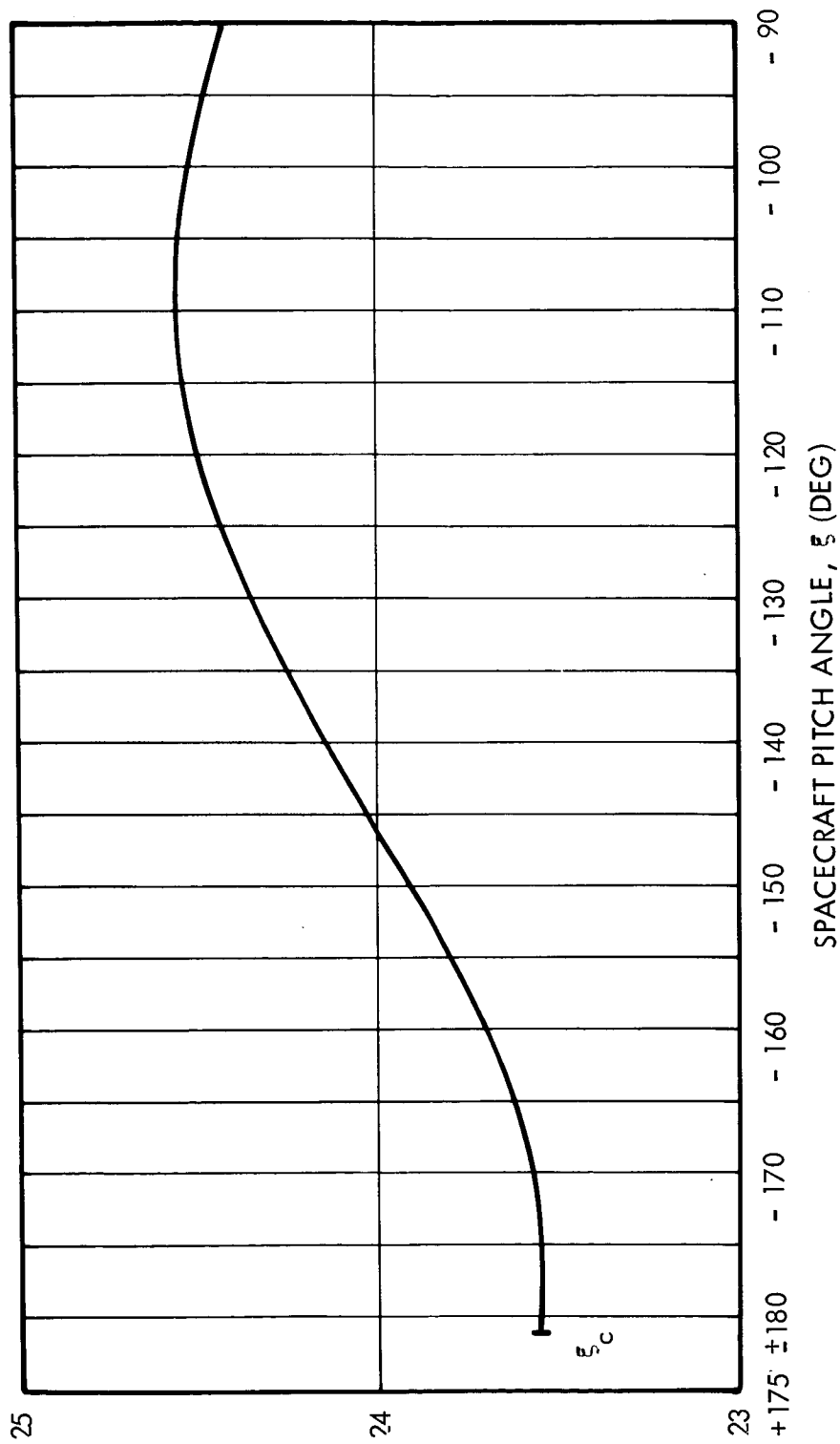
Figure 5.- Minimum Relative Separation versus Separation Pitch Angle During Nominal Entry
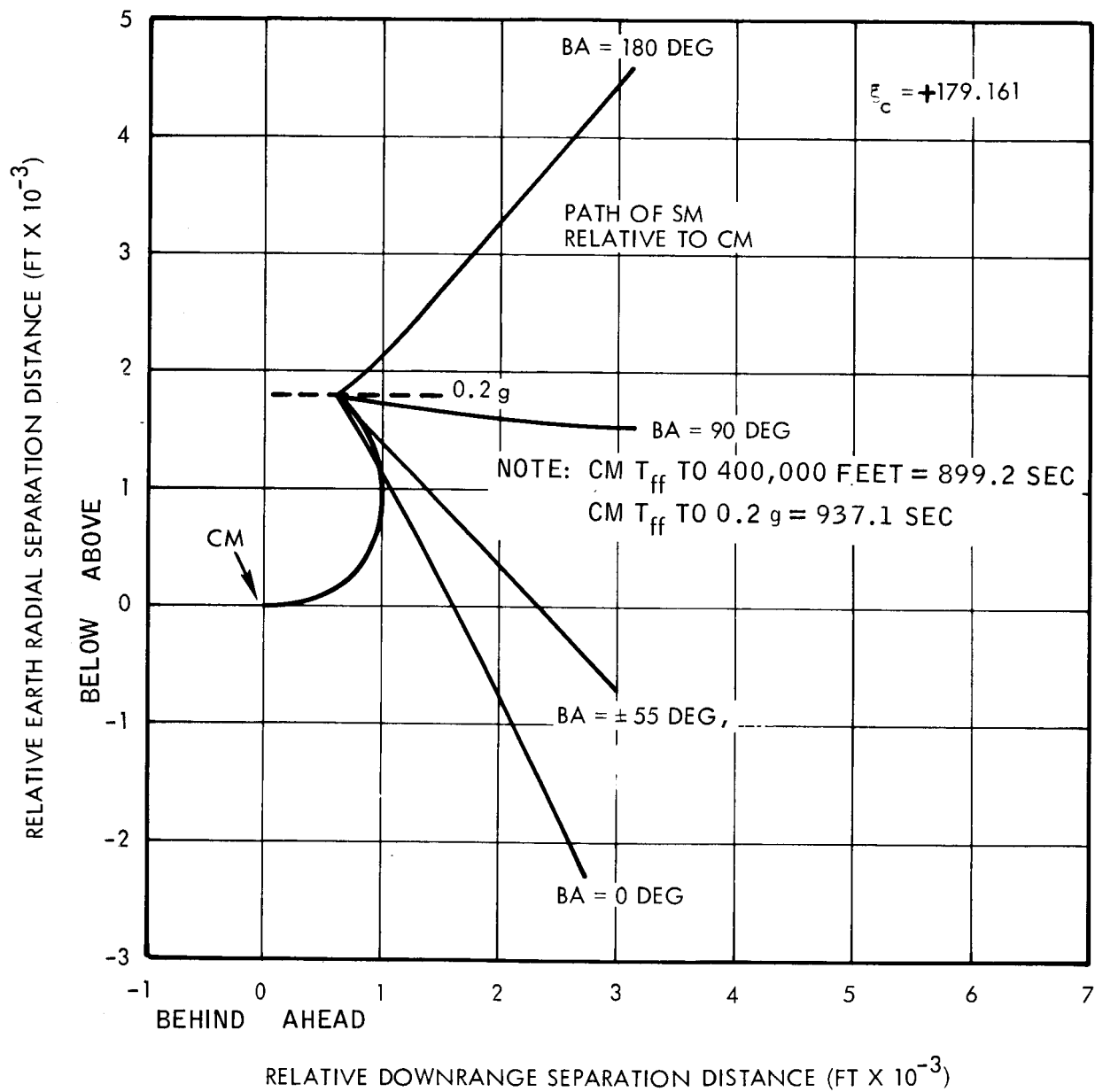
Figure 6.- Relative Downrange versus Relative Earth Radial Separation Distance Between CM and SM During Nominal Entry
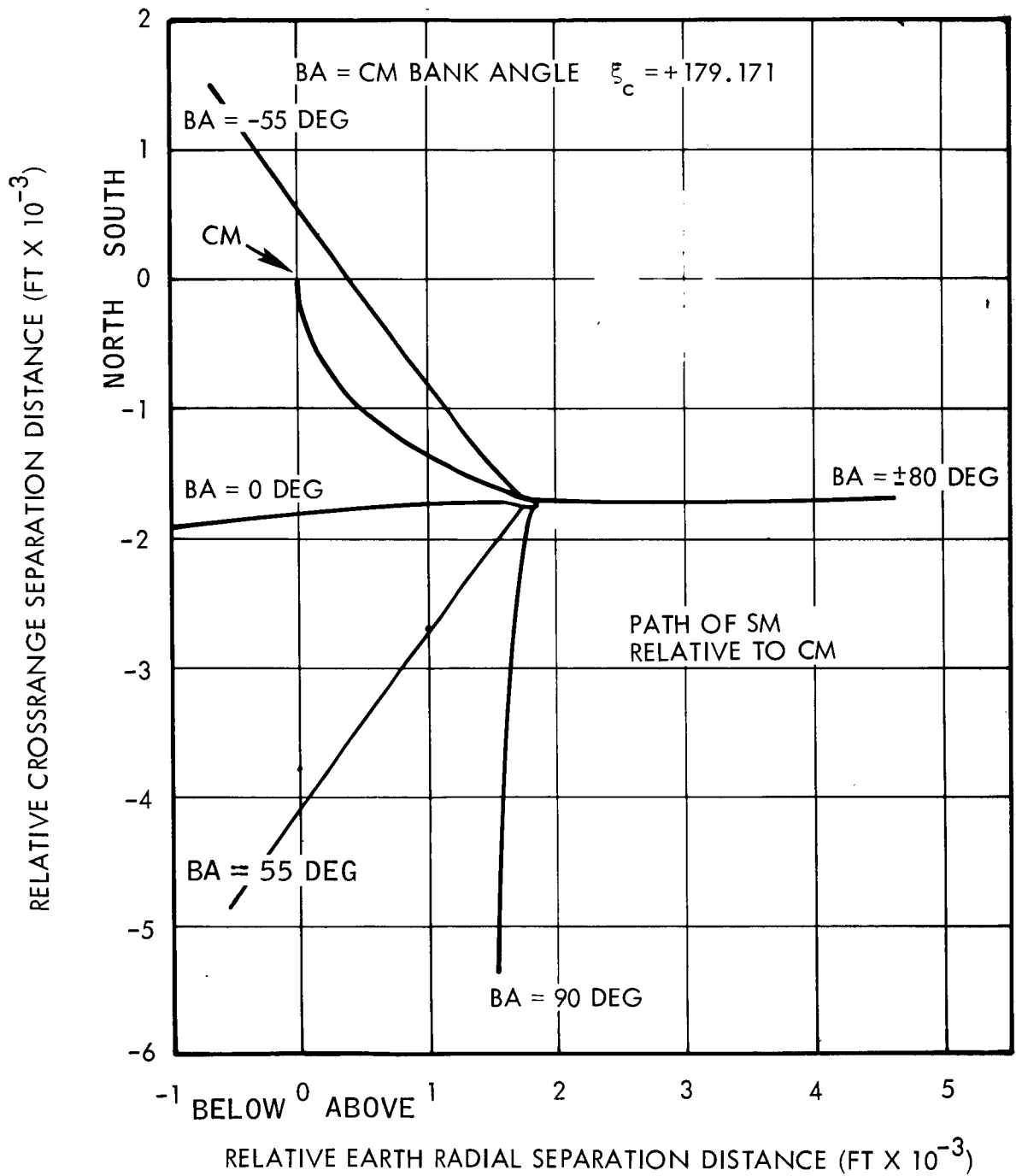
Figure 7.- Relative Crossrange versus Relative Earth
Radial Separation During Nominal Entry

CREW REACTION TIME

CRI1   Time from EDS abort light on (tumble rate reaches 10 deg/sec) to crew abort initiation

CRT2   Time from SCS enable (physical separation + 0.8 sec) to crew rate damping initiation

Recontact line for positive pitch tumble rates at EPO insertion (S-IVB cutoff)

Recontact line moves up for heavier S-IVB

No recontact region

CRT1 (SEC)

CRT2 (SEC)
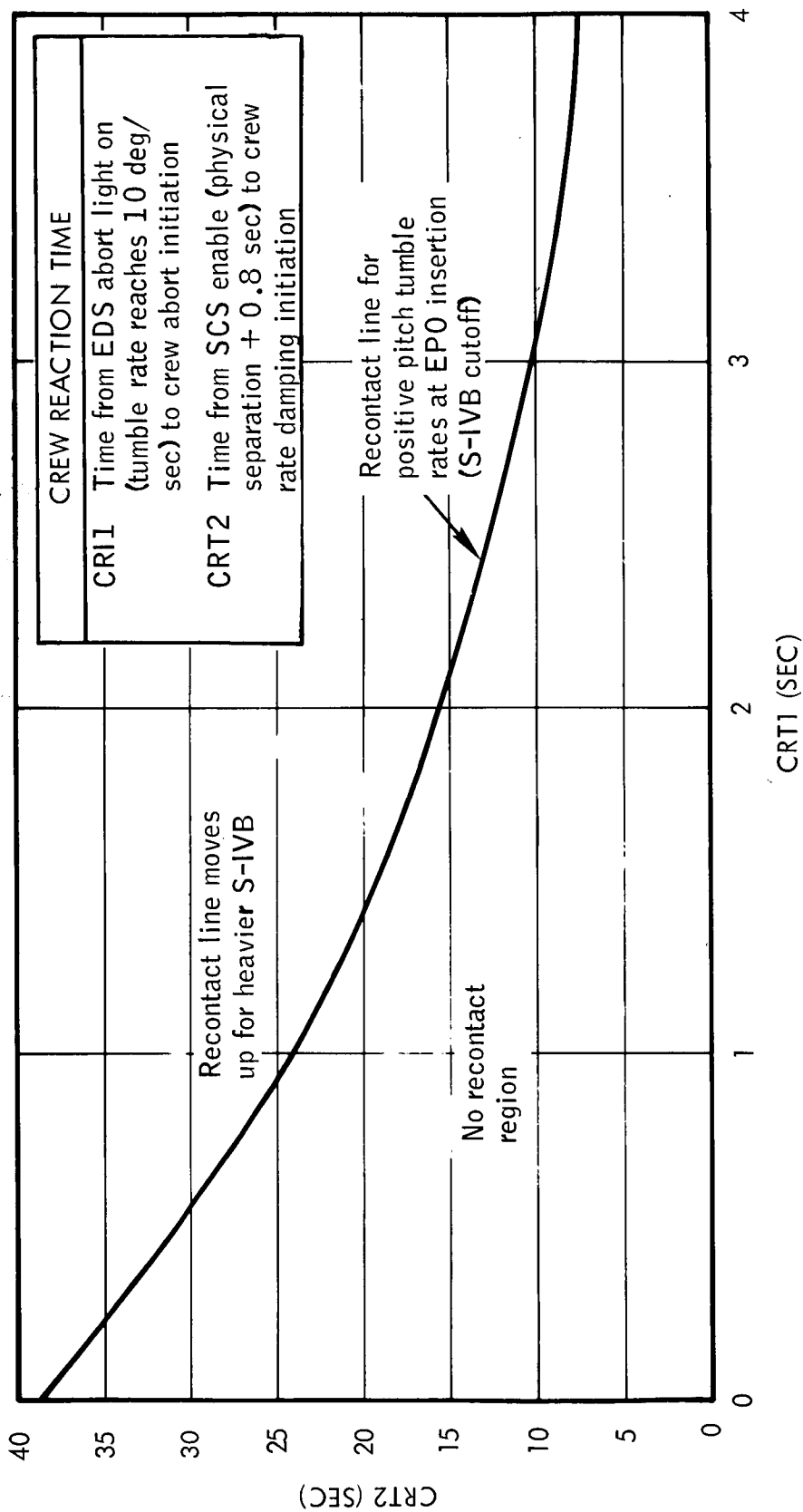
Figure 8.- Recontact Region Between CSM and S-IVB for TVC Rate Damped CSM Following S-IVB Hardover Launch Abort
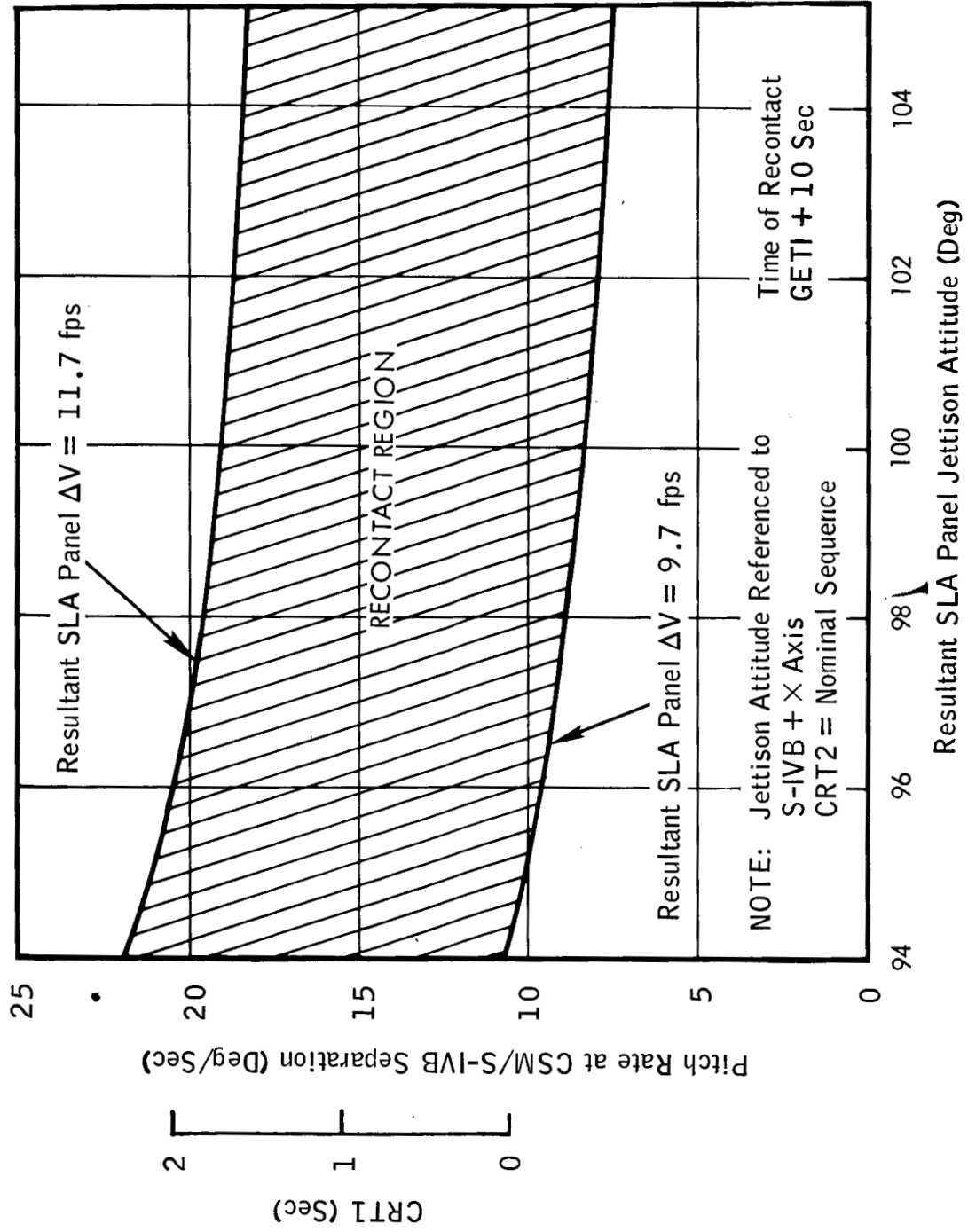
Figure 9.- Region of Recontact Between CSM and SLA Panel for an RCS Rate Damped CSM

Initial earth-fixed
attitude alignment

4.8°

Thrust vector

Line-of-sight to
far horizon
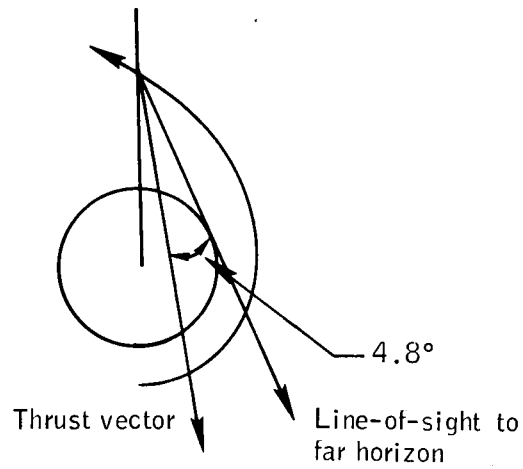
Crew referenced: crew heads up
$\left(X_b, Z_b \text{ in orbital plane} \right)$

Note: Crew aligns earth horizon
on +1 degree vertical
reticle mark.

Earth horizon

CSM c.g.
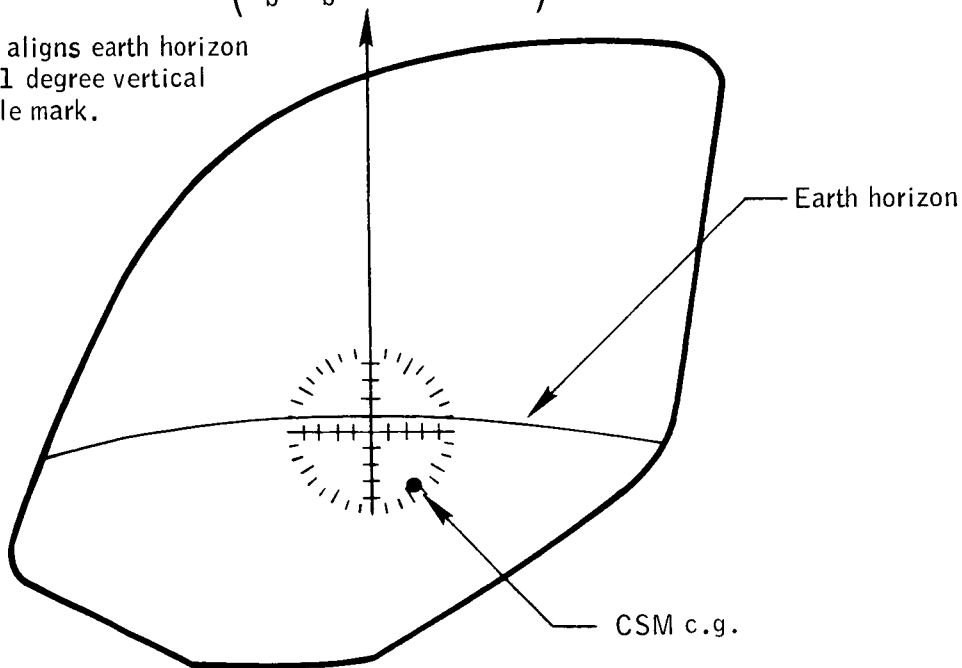
Figure 10.- Definition of attitude for fixed aborts from TLI.

Initial earth fixed
attitude alignment

V_i

6°

Thrust vector

Line-of-sight to
far horizon
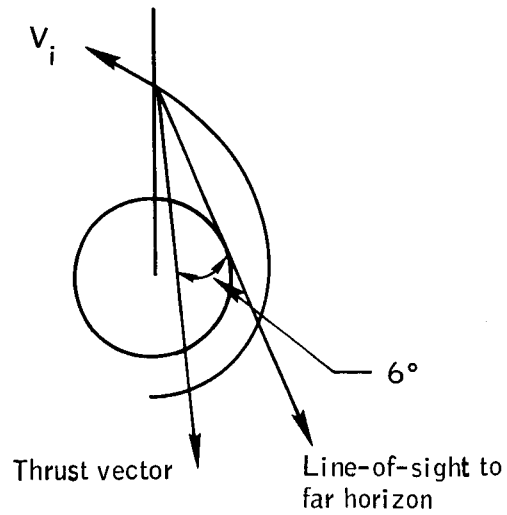
Crew referenced: crew heads up
(X_b, Z_b in-orbital plane)

Note: Earth horizon should appear
slightly above the +2 degree
vertical reticle mark.

Earth horizon

Thrust vector
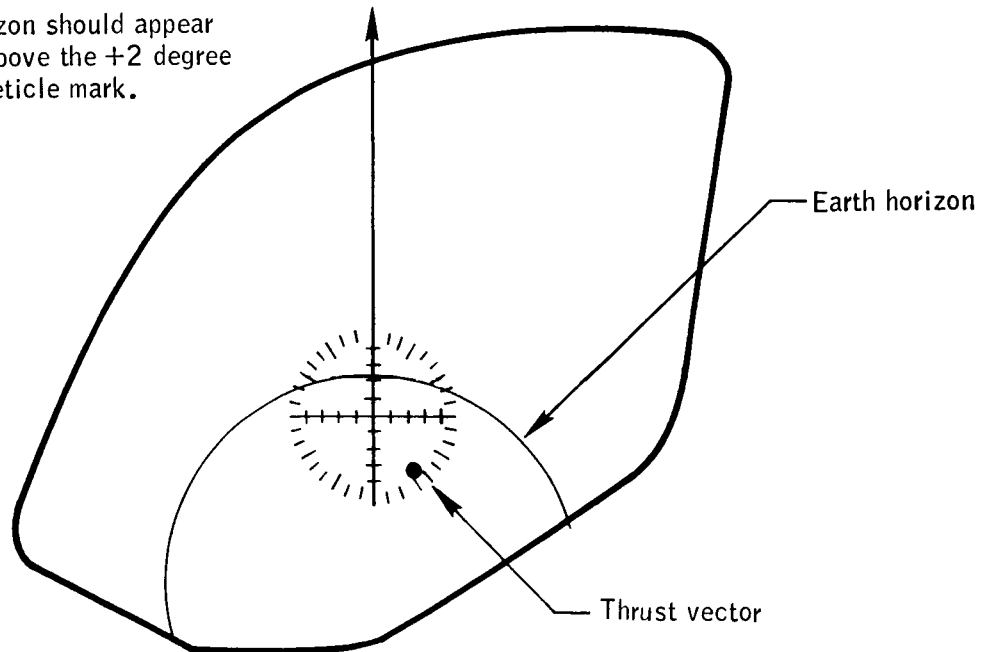
Figure 11.- Definition of attitude for TLI-plus-90-minute aborts.
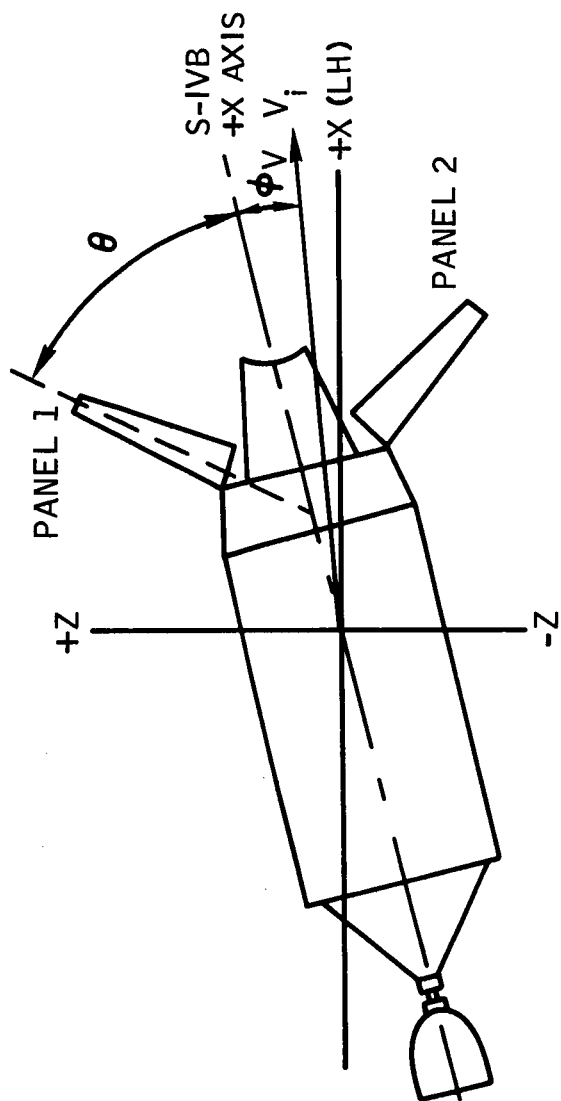
X(LH) DOWNRANGE DISPLACEMENT (LOCAL HORIZONTAL)

Z   VERTICAL DISPLACEMENT

ϕ_V S-IVB ATTITUDE WITH RESPECT TO V_i

θ PANEL JETTISON ATTITUDE (PITCH)

(a) Pitched panels (X -Z plane).

Figure 12.- S-IVB and SLA panel attitude identification.
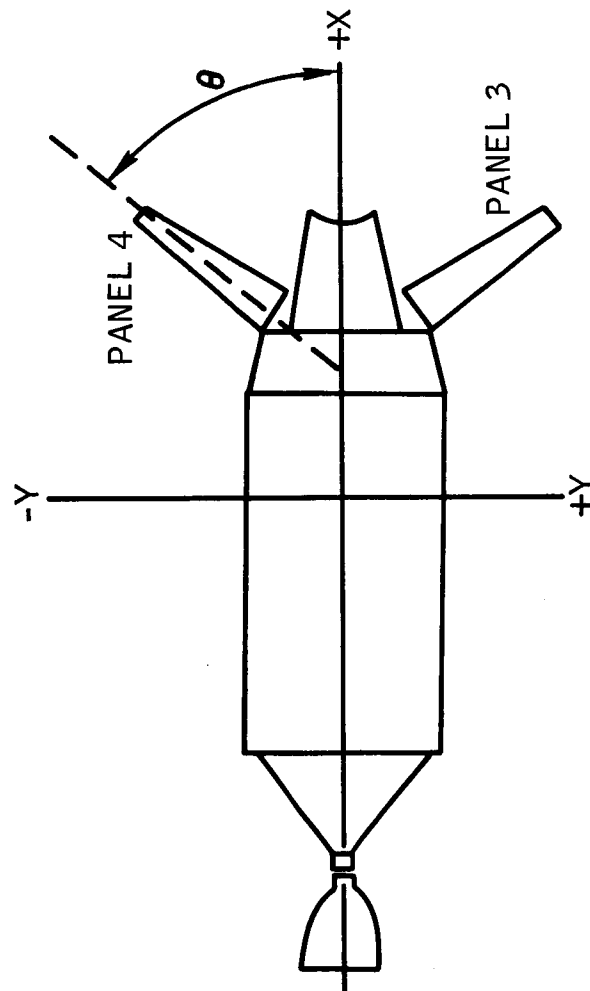
X   DOWNRANGE DISPLACEMENT

Y   LATERAL DISPLACEMENT

θ   PANEL JETTISON ATTITUDE (YAW)

(b) Yawed panels (X –Y plane).

Figure 12.– Continued.
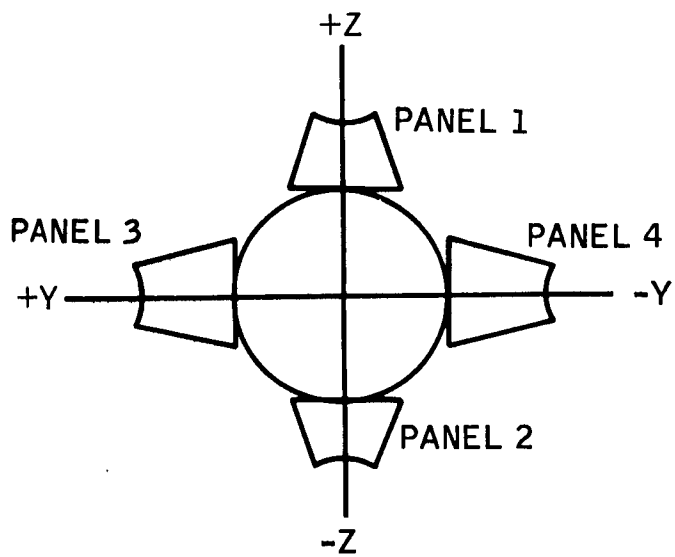
(c) Front view (Y-Z plane).

Figure 12.- Concluded.
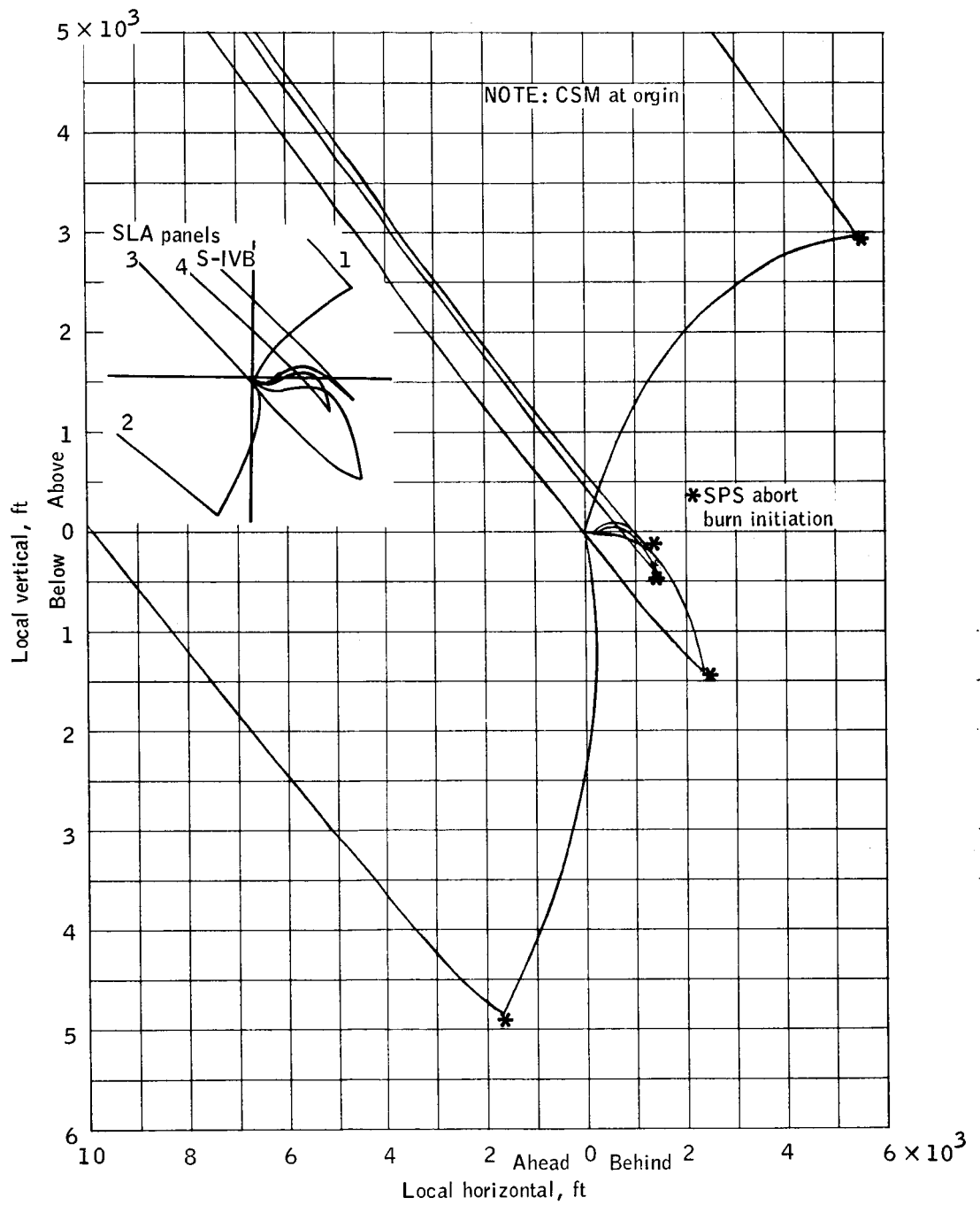
(a) Local horizontal versus local vertical range.

Figure 13.- Radially inward evasive maneuver for mid-TLI abort relative motion of the S-IVB and SLA panels with respect to the CSM.
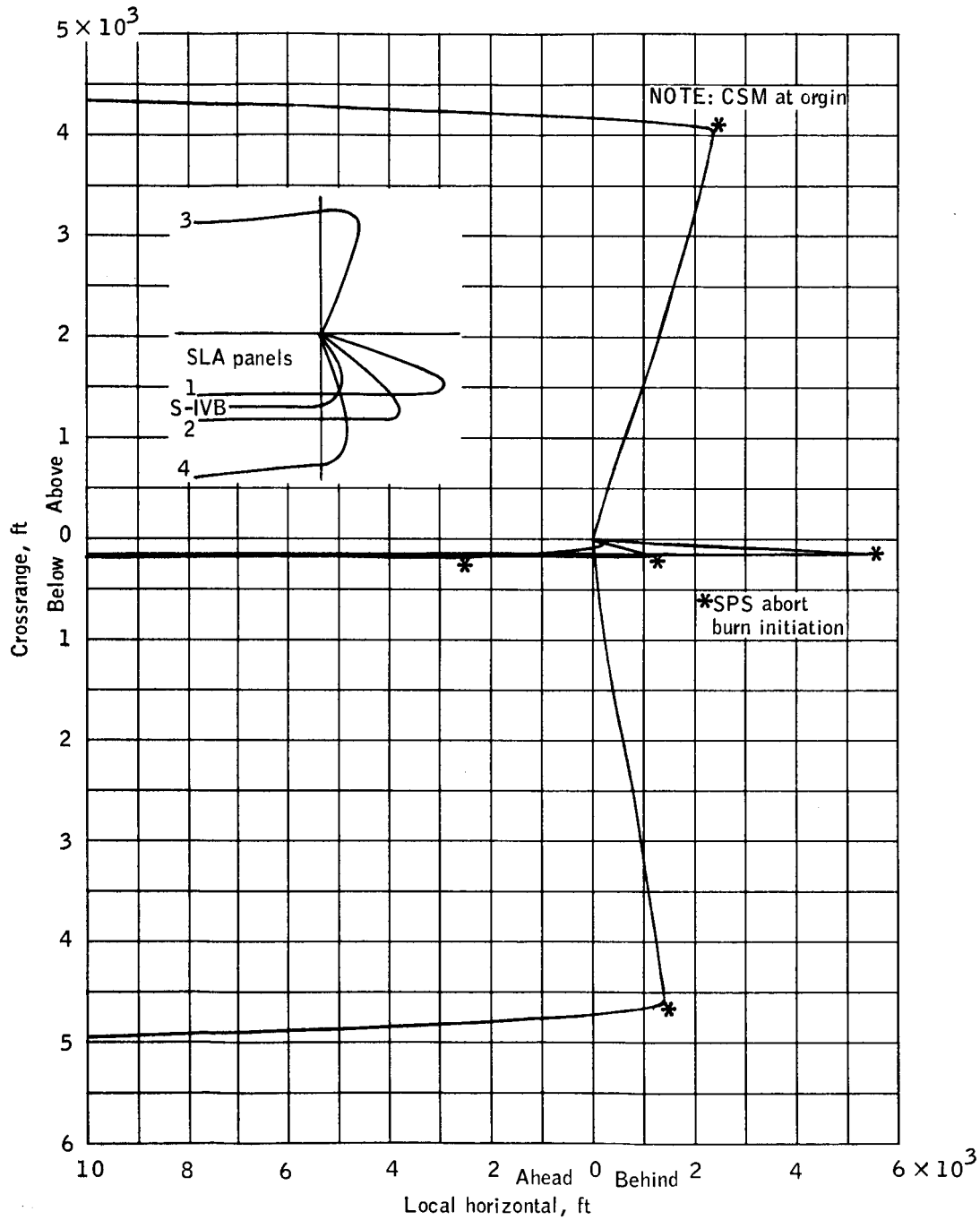
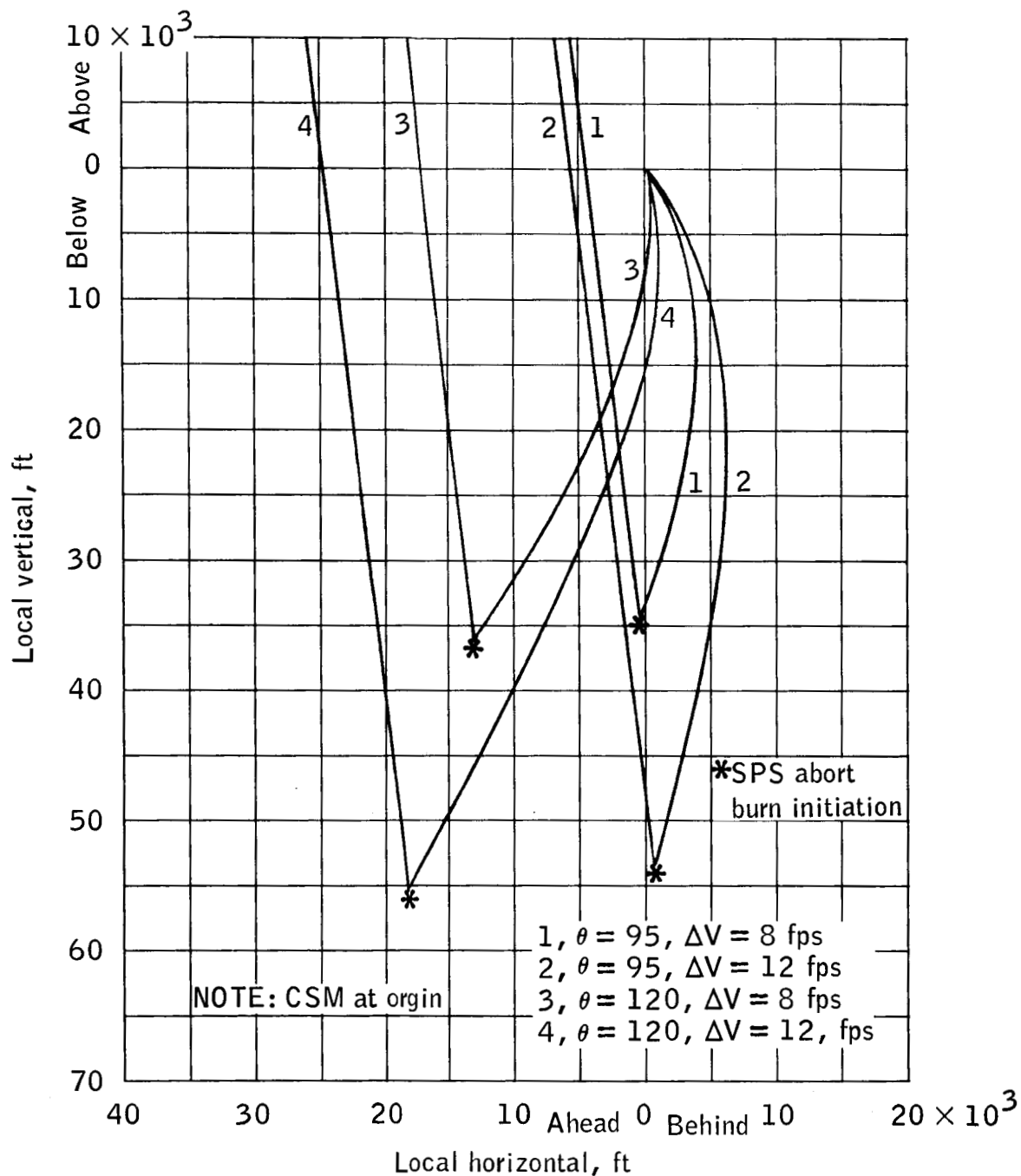(b) Local horizontal versus crossrange.

Figure 13.- Concluded.
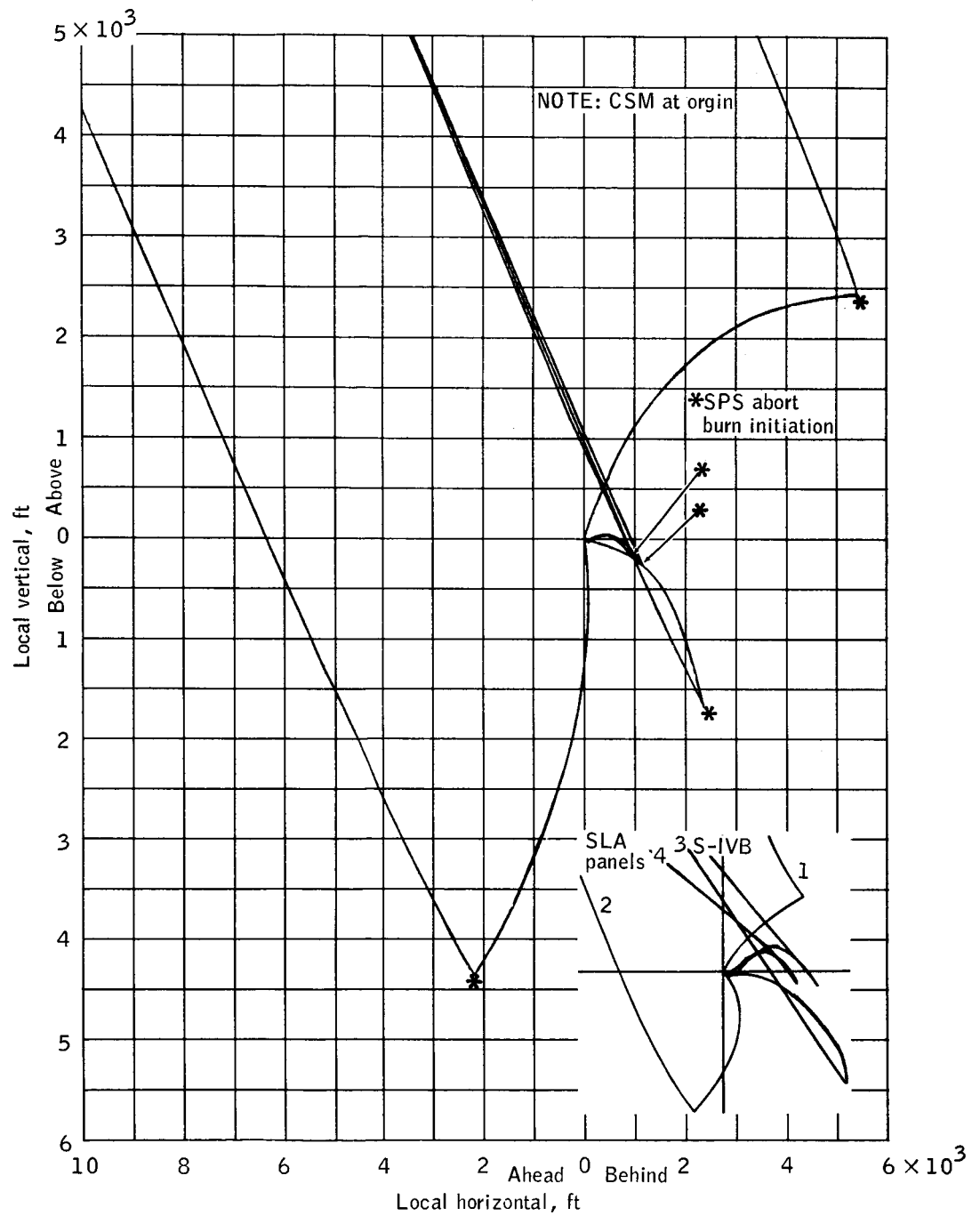
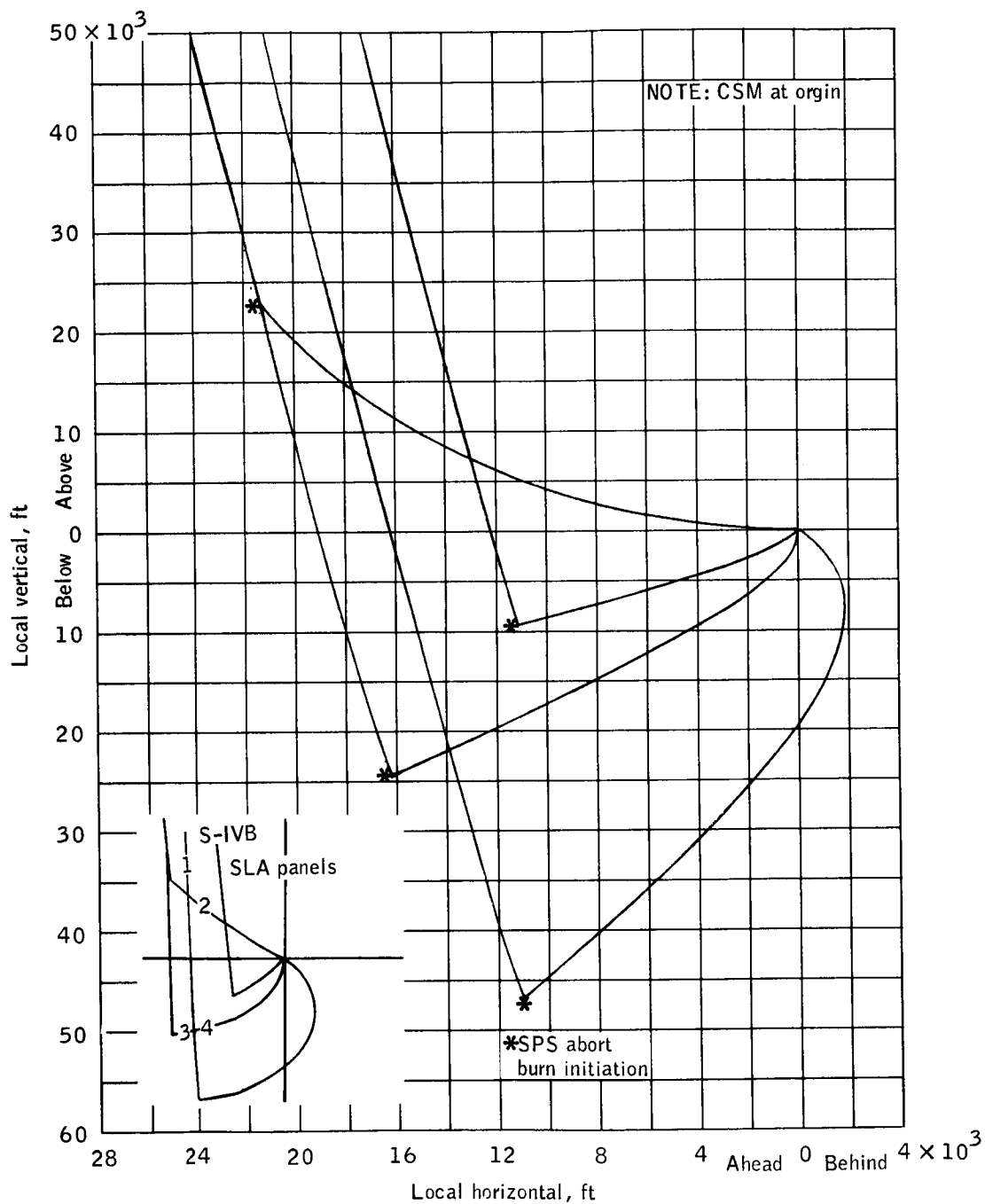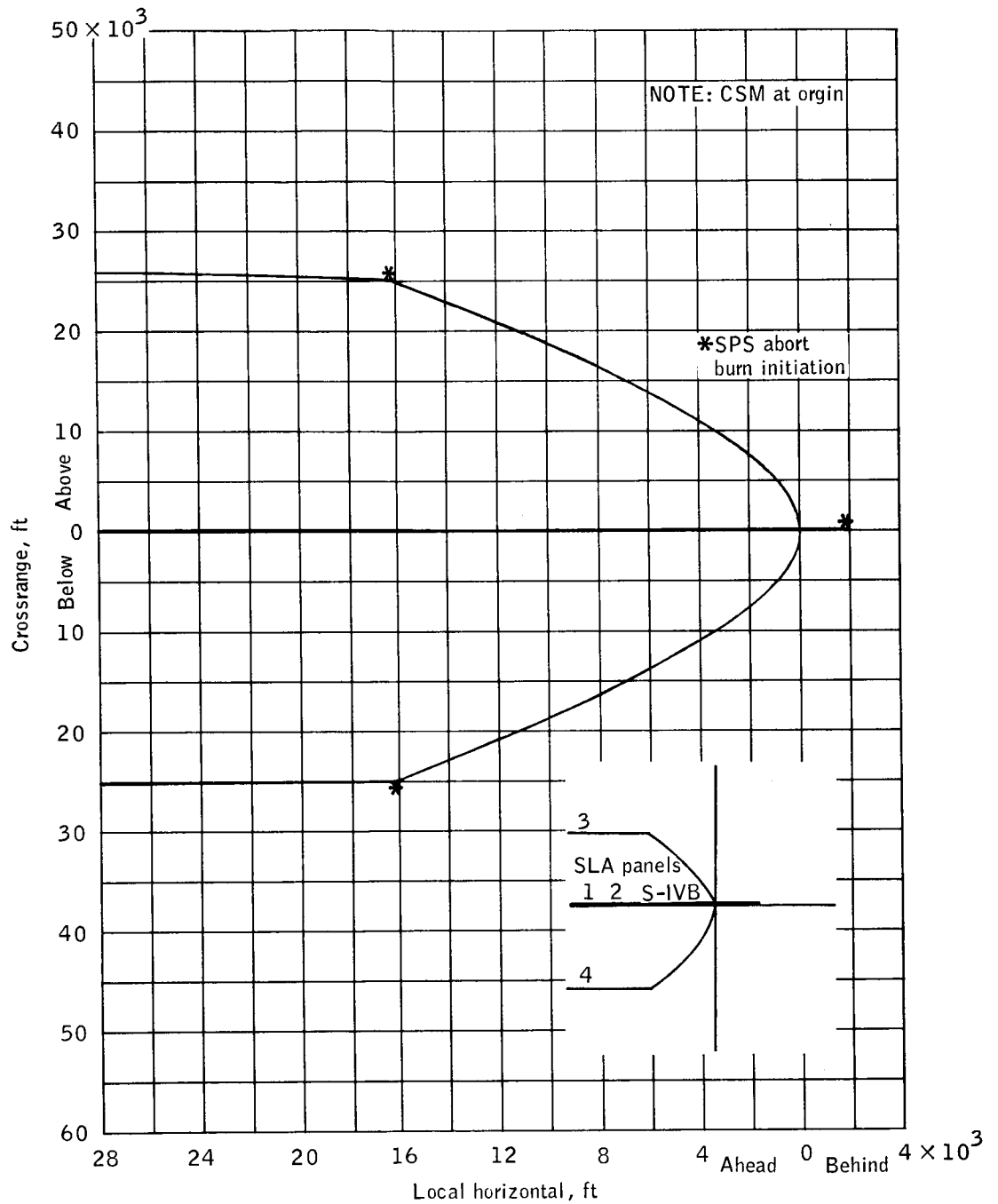(a) Local horizontal versus local vertical range.

Figure 14.- Radially inward evasive maneuver for late-TLI abort relative motion of the S-IVB and SLA panels with respect to the CSM.
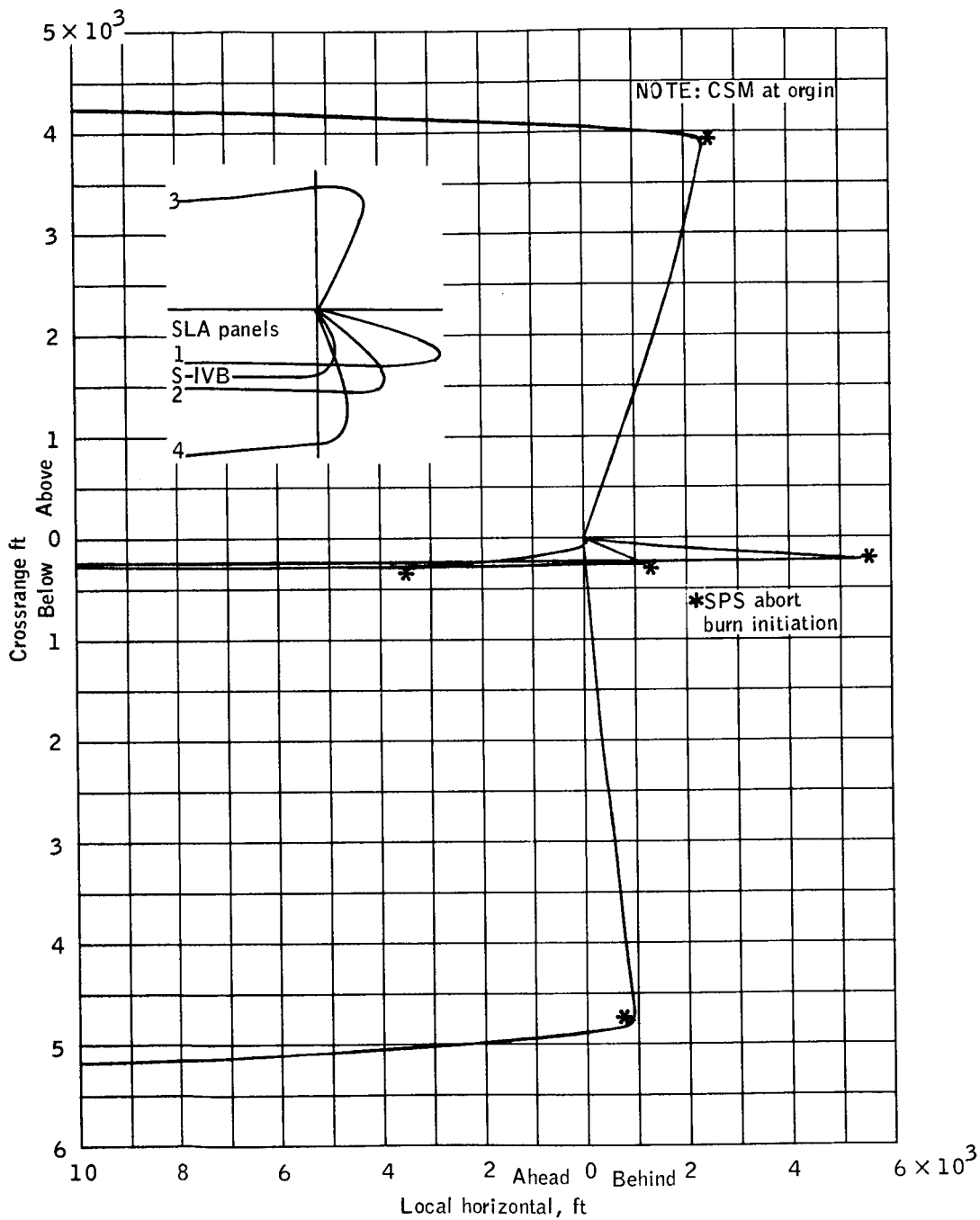
(b) Local horizontal versus crossrange.

Figure 14.- Concluded.
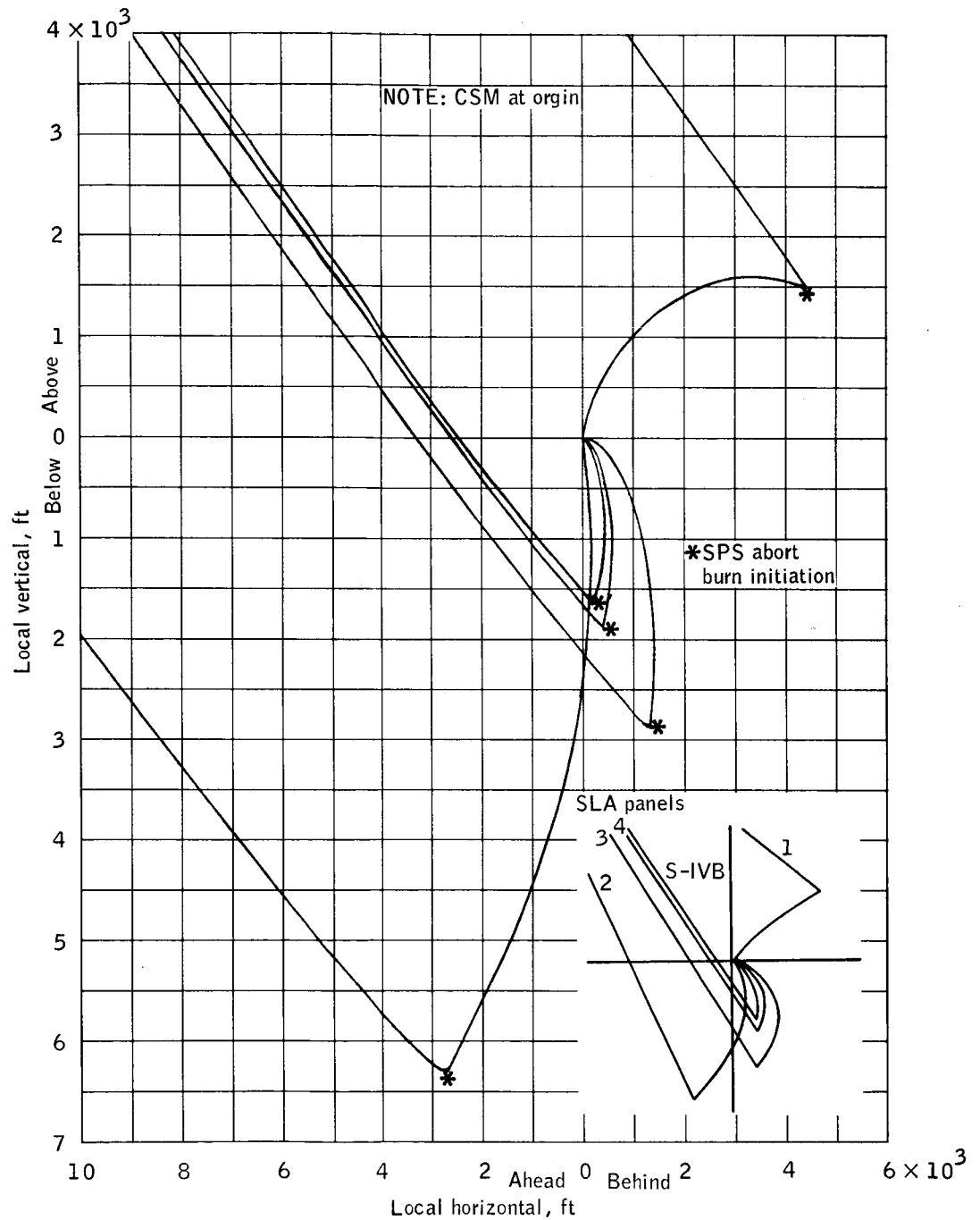
(a) Local horizontal versus local vertical range.

Figure 15.- Radially outward evasive maneuver for mid-TLI abort relative motion of the S-IVB and SLA panels with respect to the CSM.
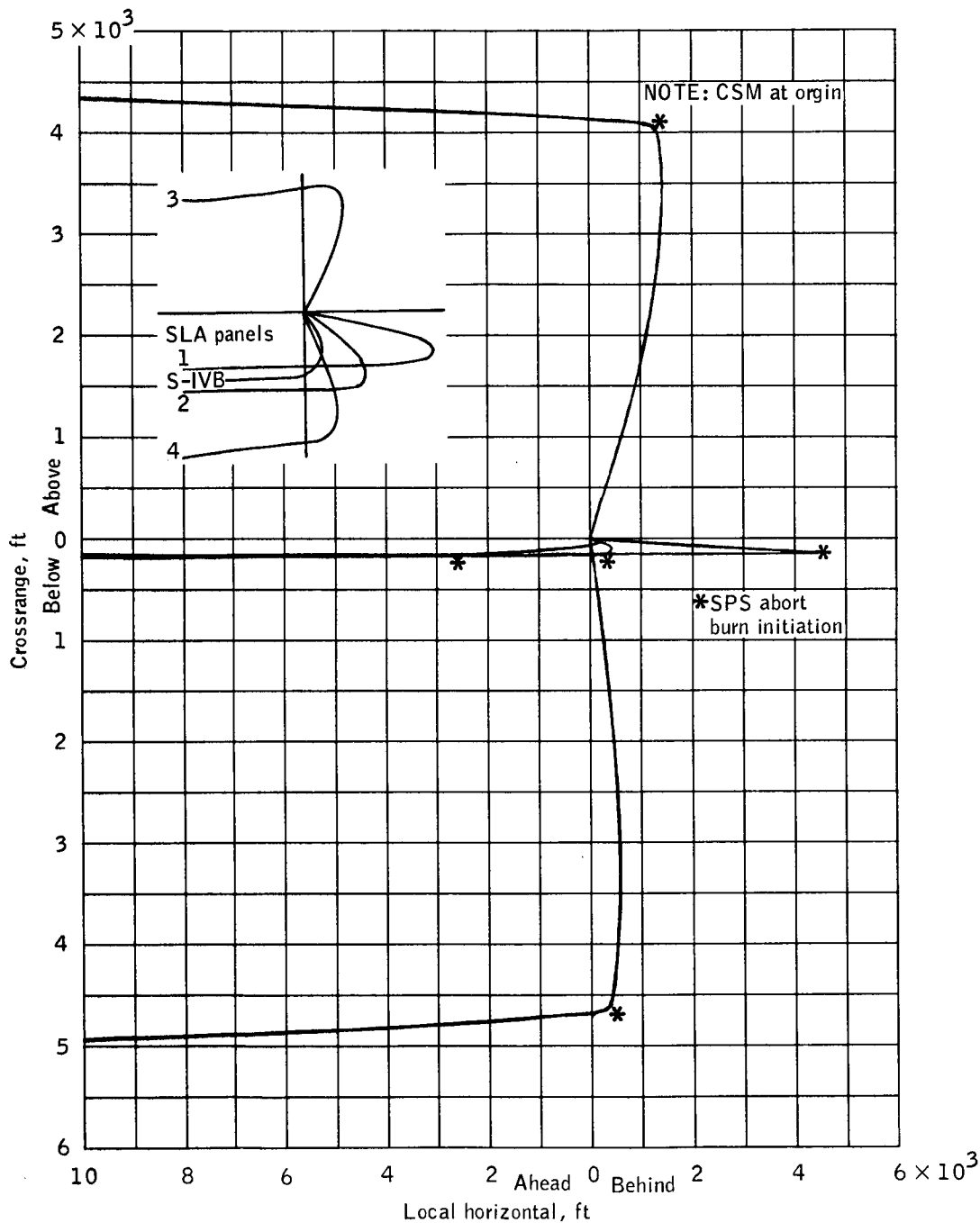
(b) Local horizontal versus crossrange.

Figure 15.- Concluded.
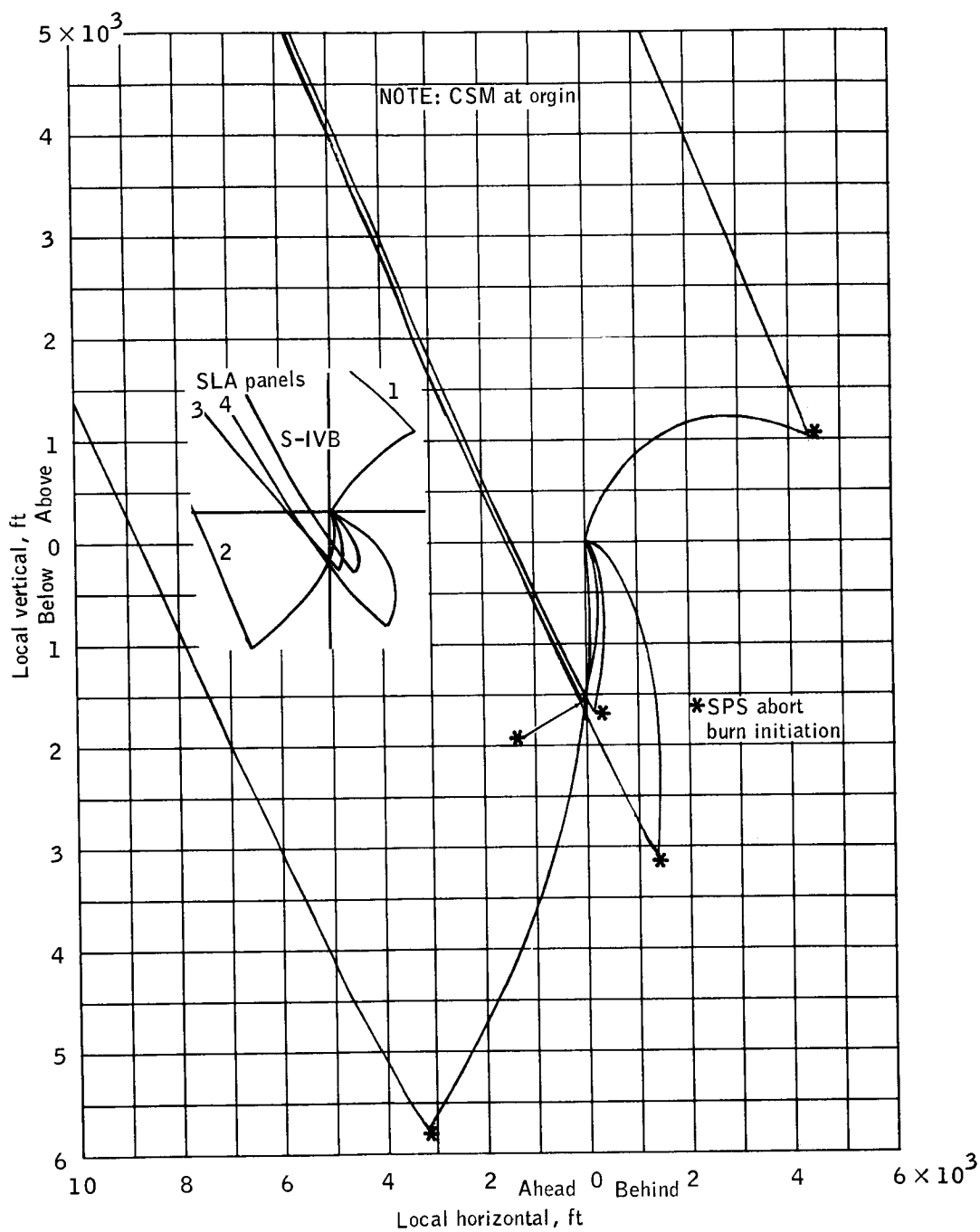
(a) Local horizontal versus local vertical range.

Figure 16.- Radially outward evasive maneuver for late-TLI abort relative motion
of the S-IVB and SLA panels with respect to the CSM.
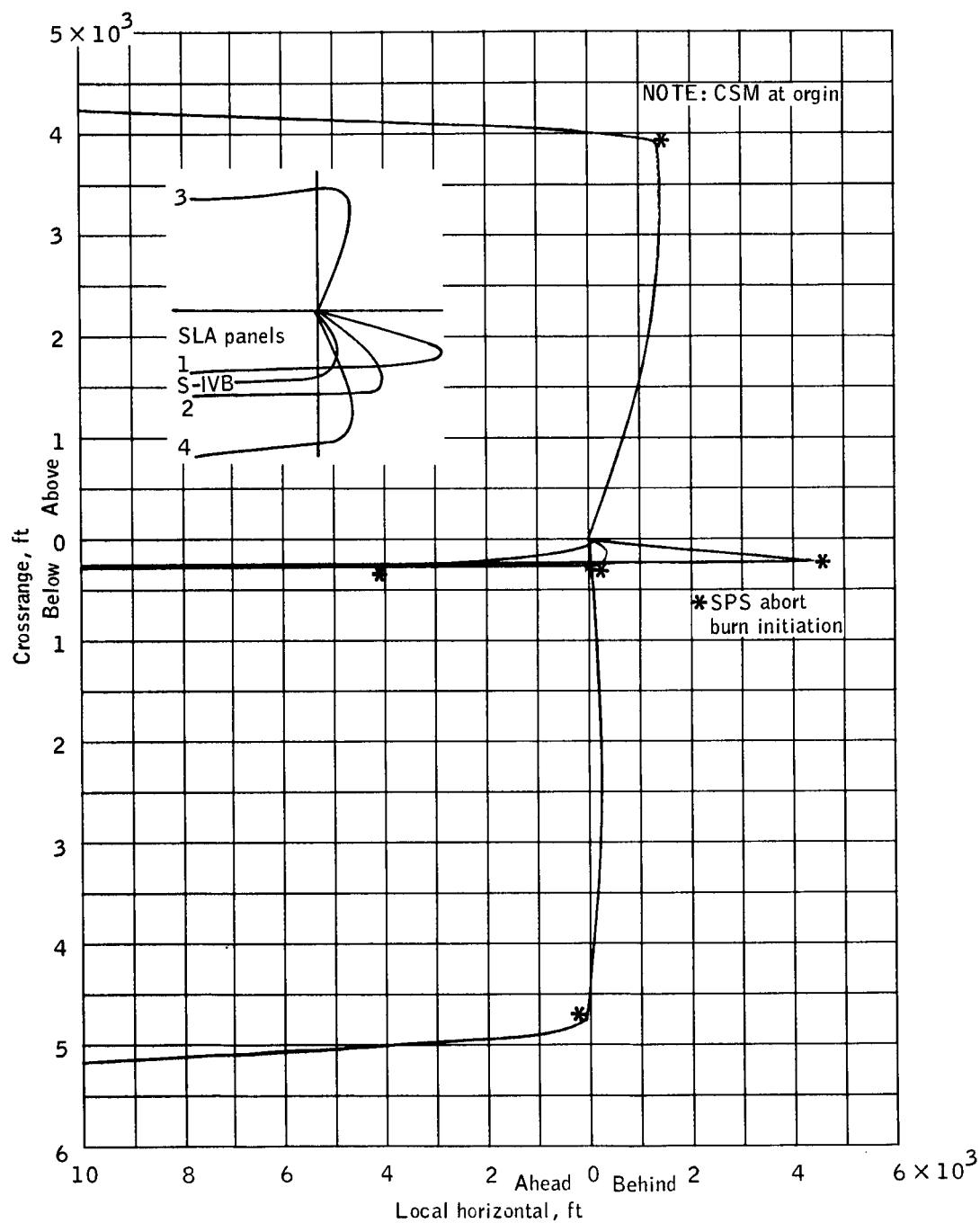
(b) Local horizontal versus crossrange.

Figure 16.- Concluded.
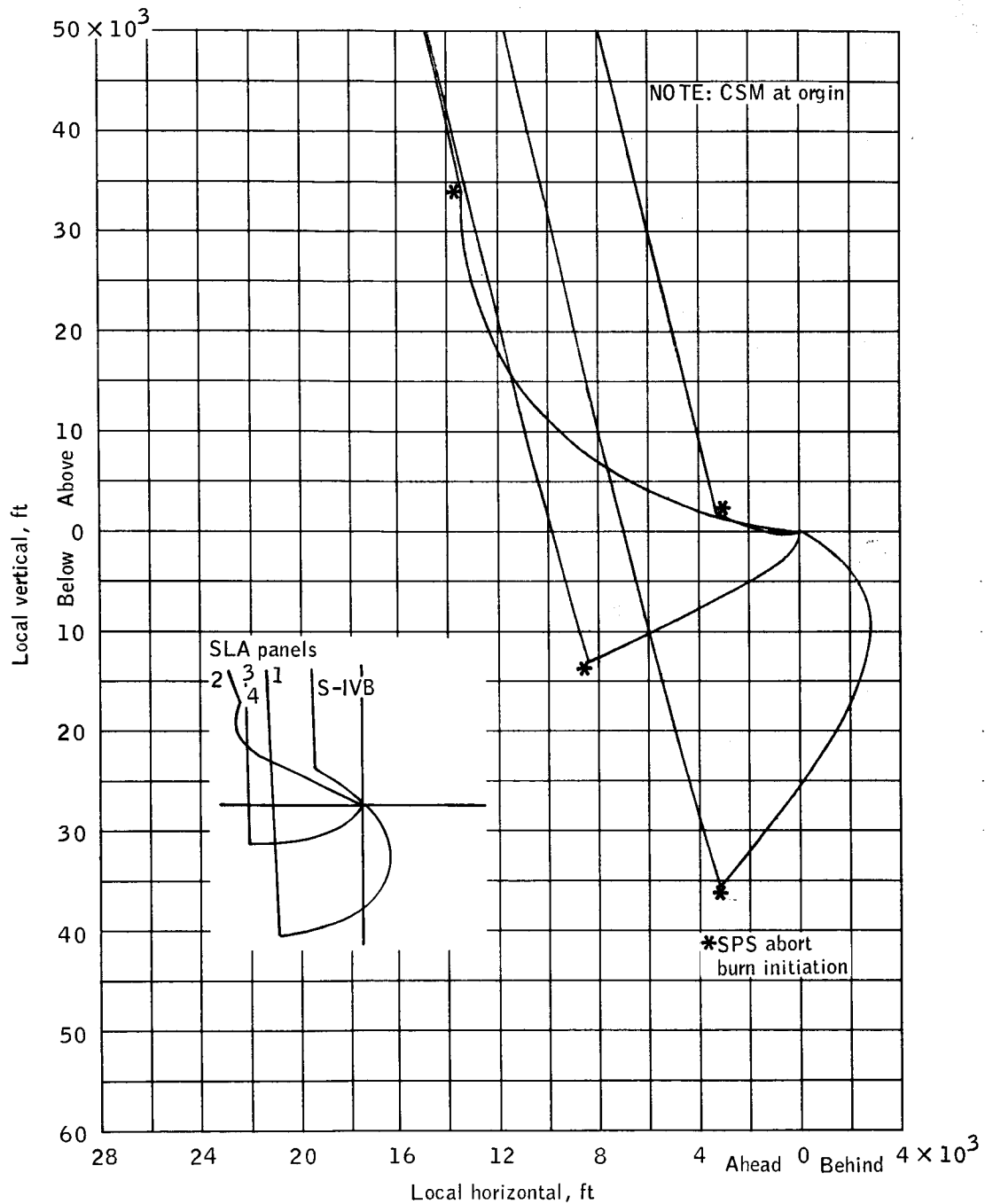
(a) Local horizontal versus local vertical range.

Figure 17.- Radially inward evasive maneuver for 90 minute TLC relative motion of the S-IVB and SLA panels with respect to the CSM.
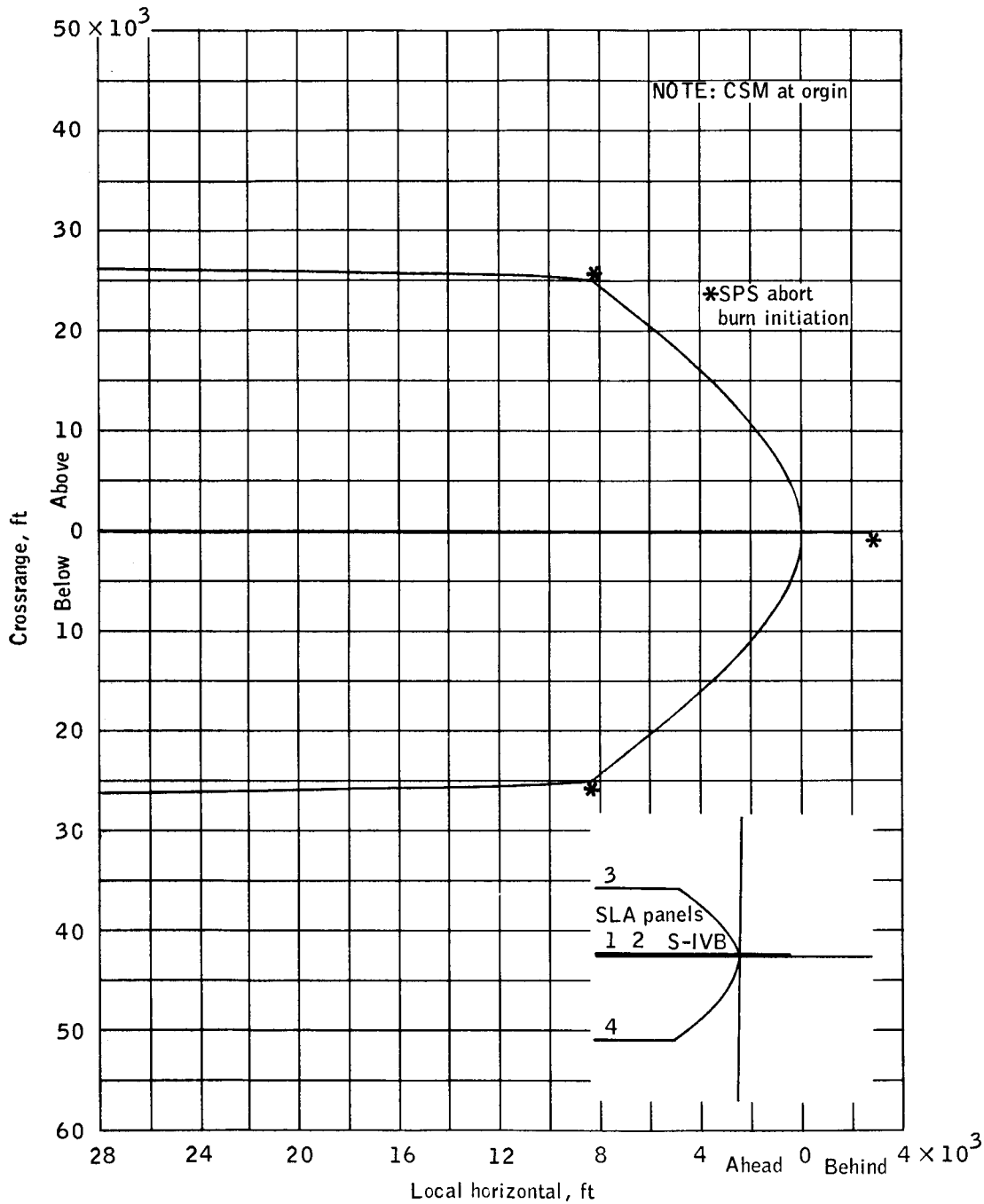
(b) Local horizontal versus crossrange.

Figure 17.- Concluded.

Figure 18.- TLC 90 minute abort relative motion of SLA
panel 1 with respect to the CSM for radially inward
evasive maneuver.

(a) Local horizontal versus local vertical range.

Figure 19.- Radially outward evasive maneuver for 90 minute TLC relative motion of the S-IVB and SLA panels with respect to the CSM.

(b) Local horizontal versus crossrange.

Figure 19.- Concluded.
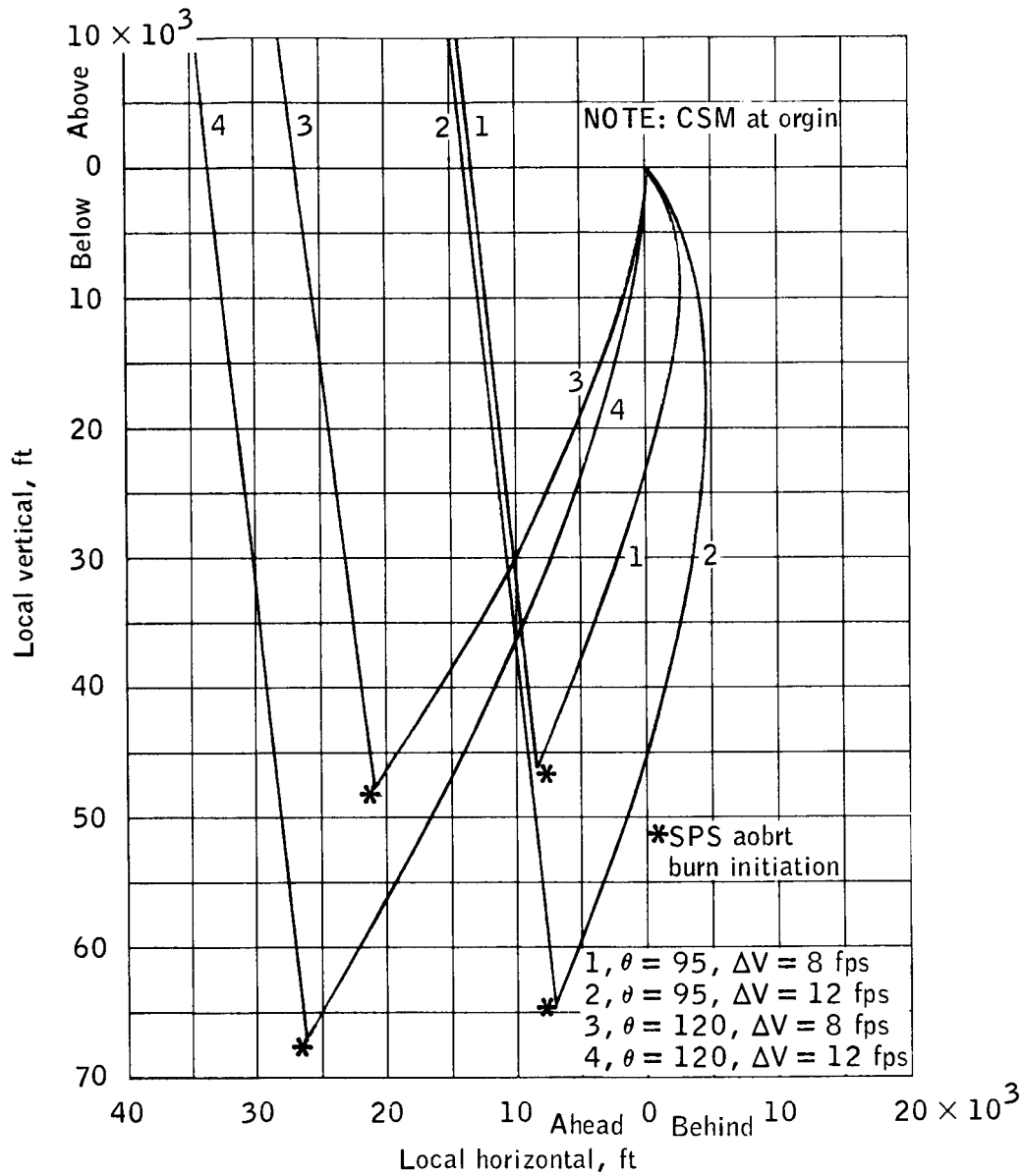
Figure 20.- TLC 90 minute abort relative motion of SLA
panel 1 for radially outward evasive maneuver.

65
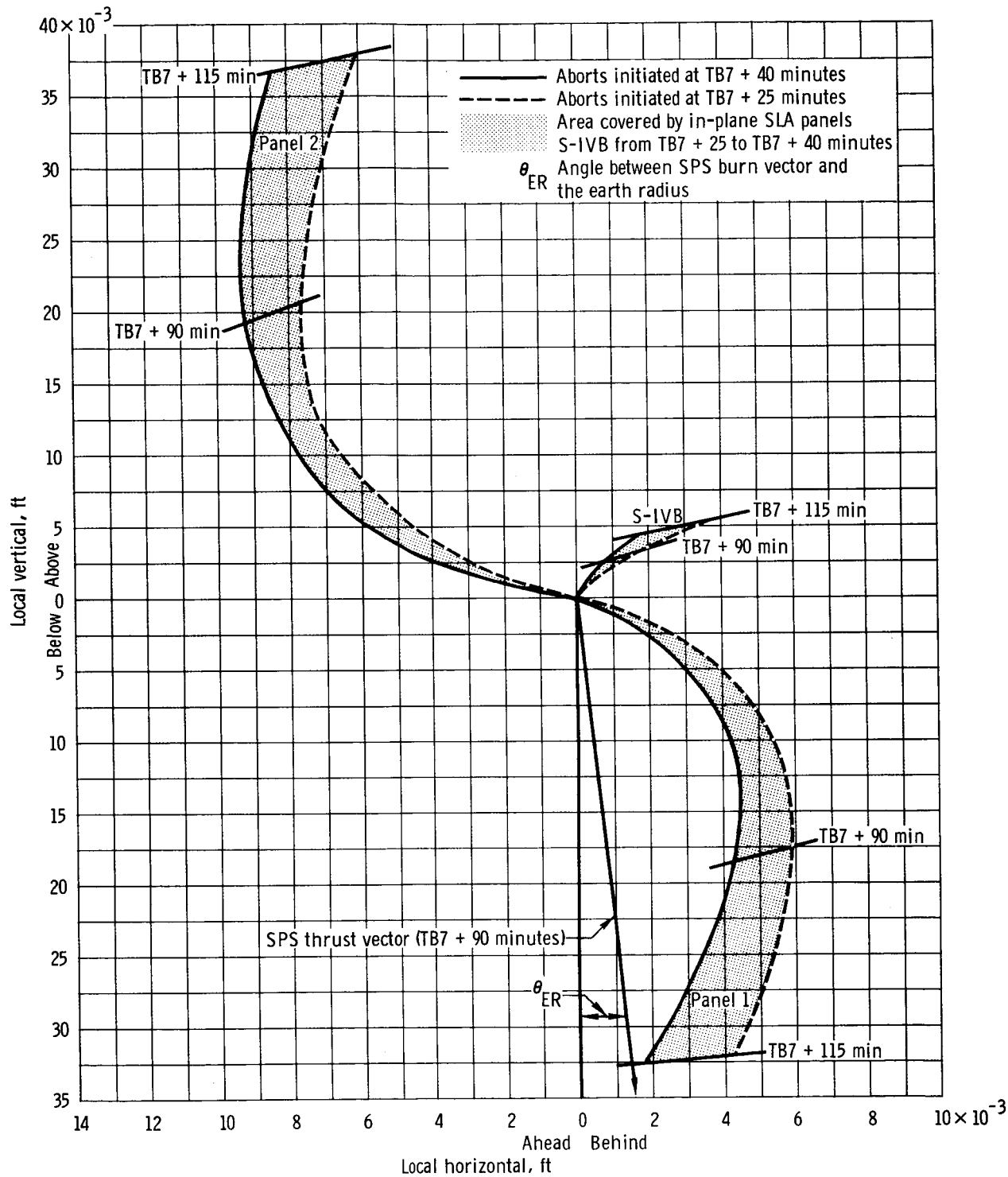
Figure 21.- In-plane SLA panels and S-IVB motion relative to the CSM for aborts initiated from TB7 + 25 minutes to TB7 + 40 minutes; radially inward evasive maneuver.
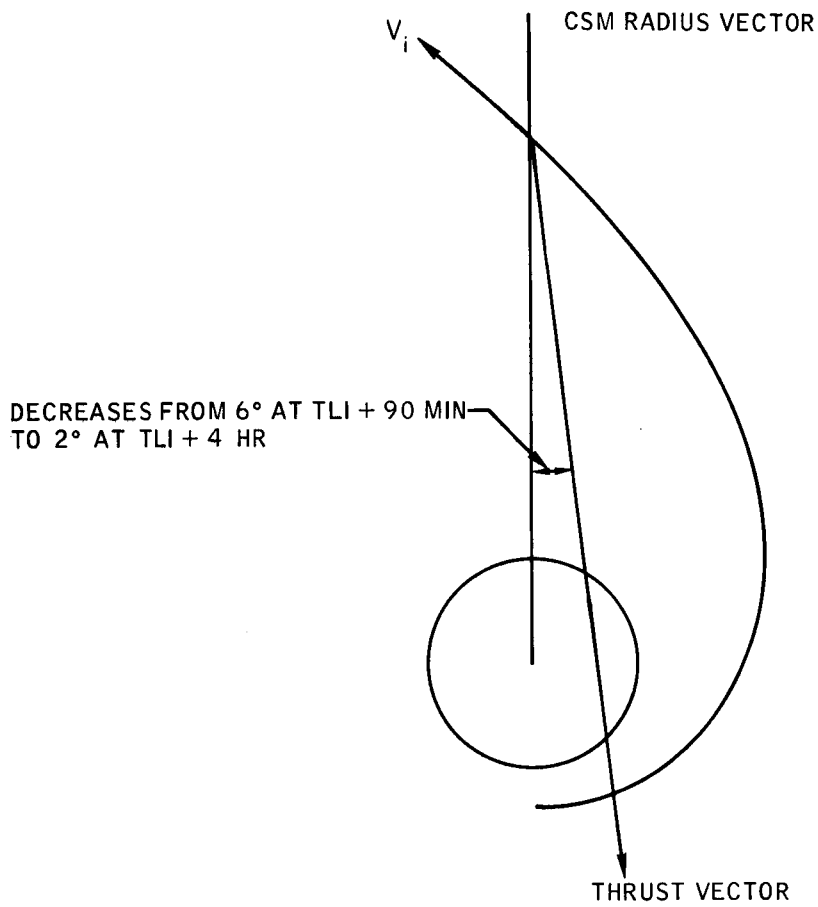
Figure 22.- TLC Abort ΔV Attitude Reference
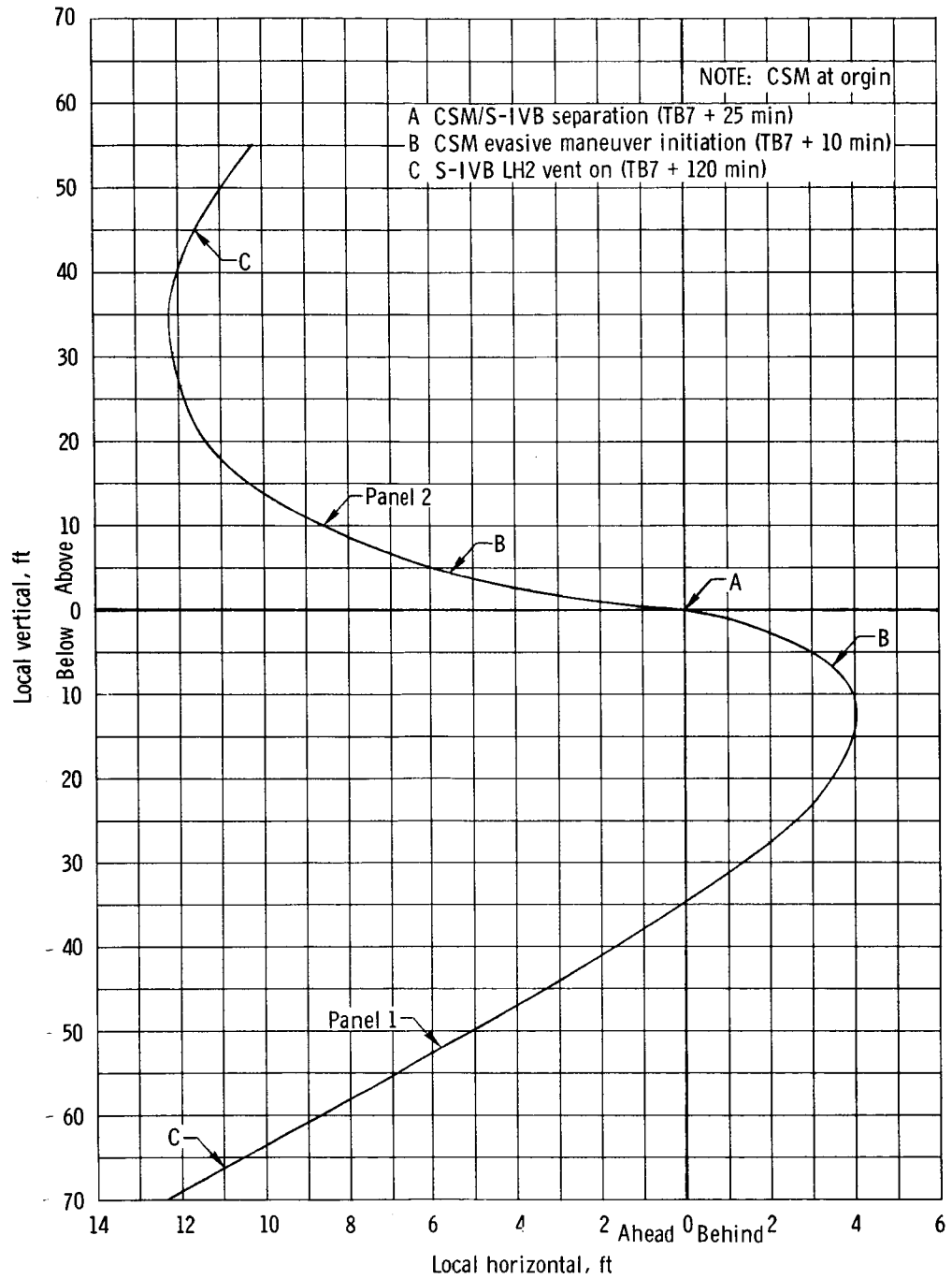
Figure 23. - SLA panel 1 and 2 relative motion with respect to the CSM during the nominal evasive maneuver.
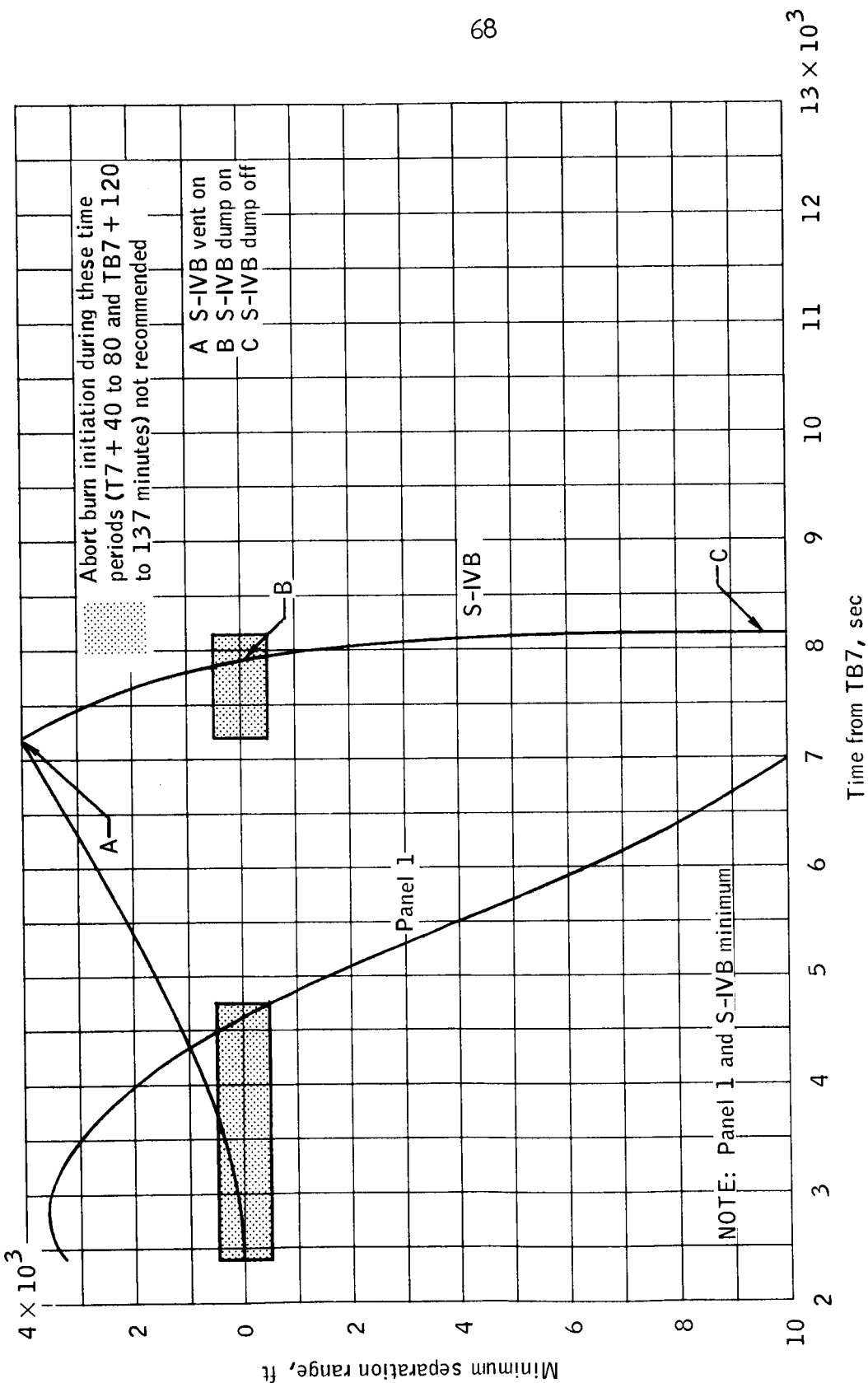
Figure 24.- Minimum separation range versus time for the CSM with respect to the S-IVB and panel 1 for a CSM SPS abort burn initiated during the post-TLI nominal evasive maneuver.
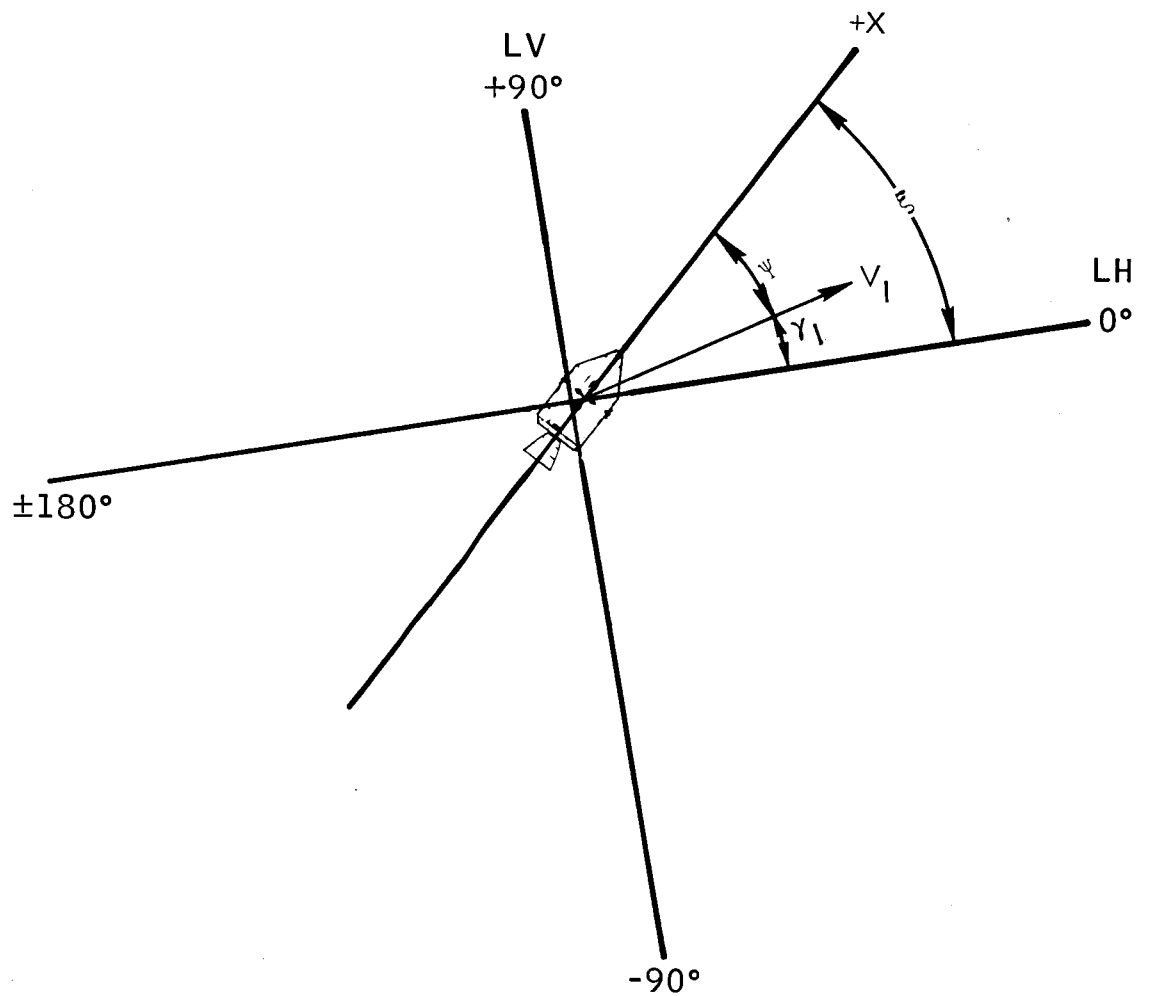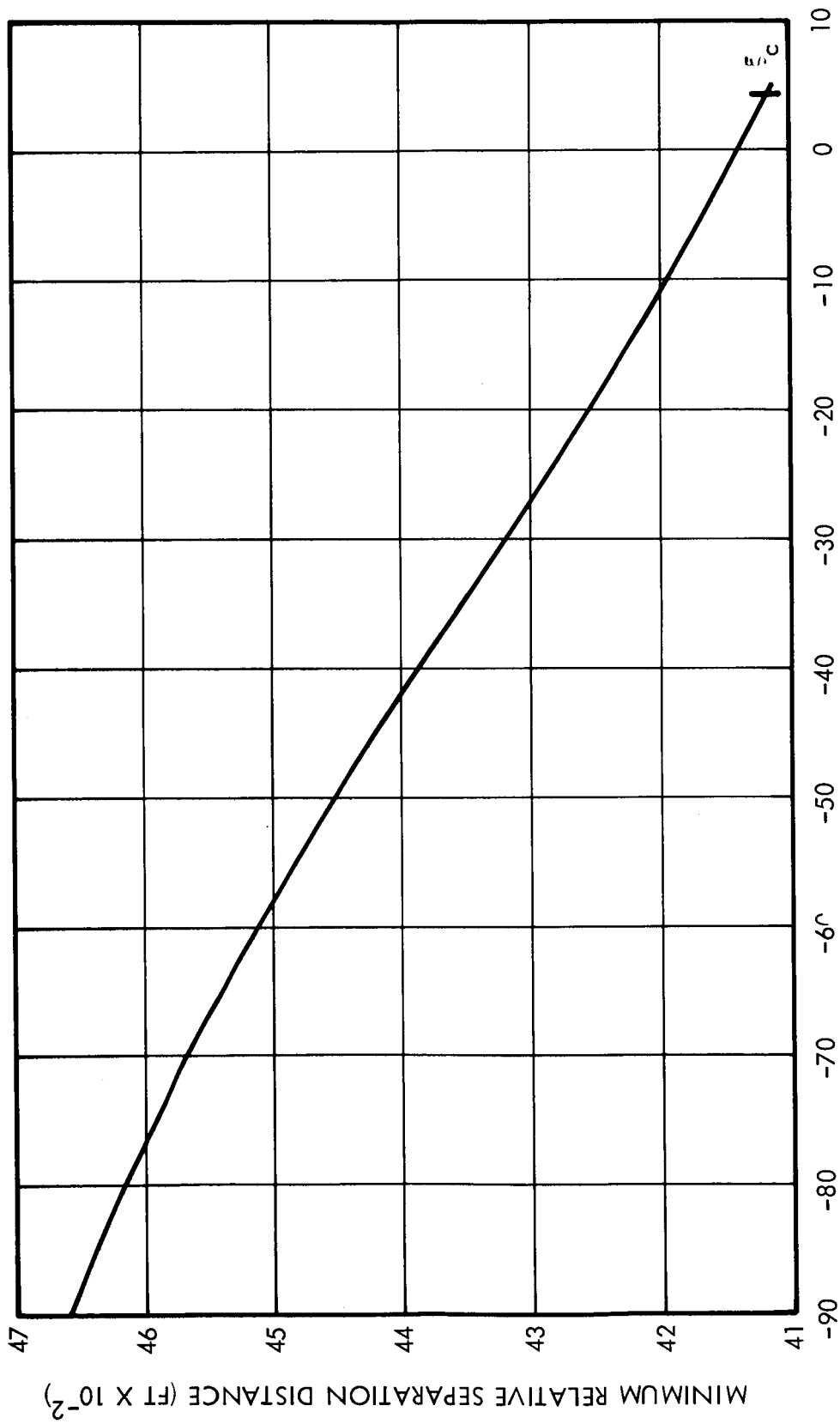
Figure 25.- CSM Attitude for CSM/SM Separation Following
Mode II Abort

SPACECRAFT PITCH ANGLE, ξ (DEG)

Figure 26.— Minimum Relative Separation Distance versus Separation Pitch Angle ξ During Entry Following Mode II Abort
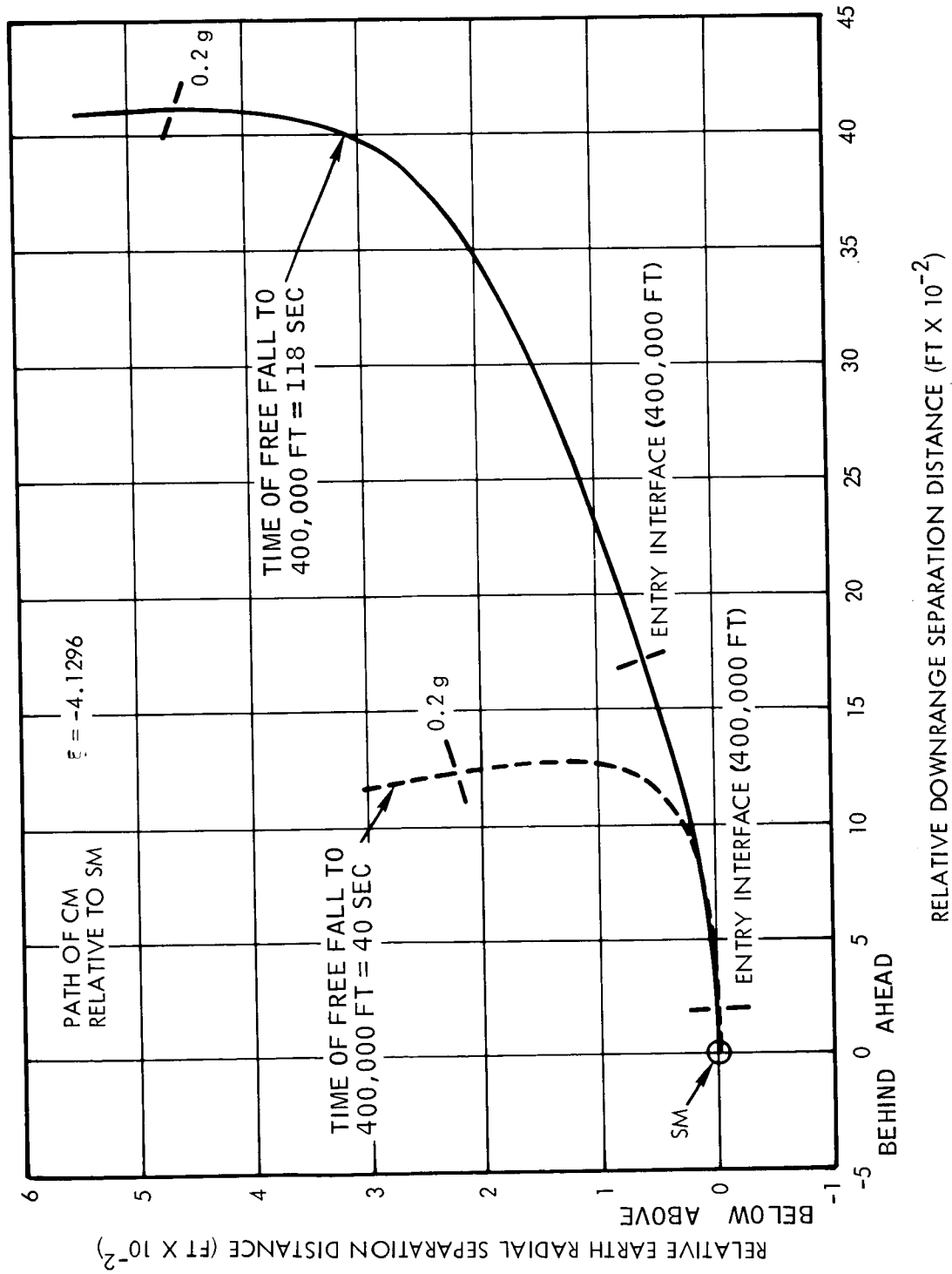
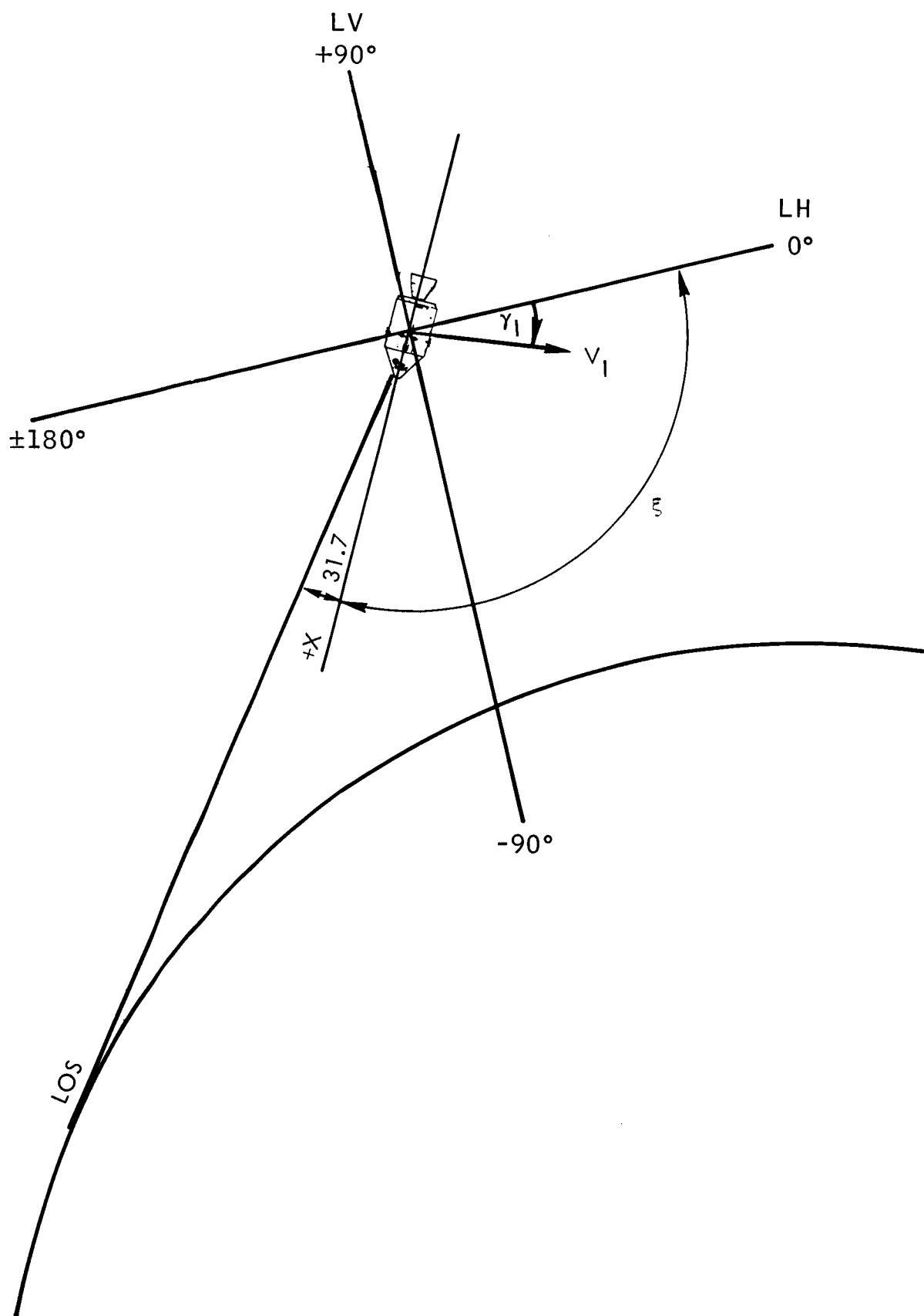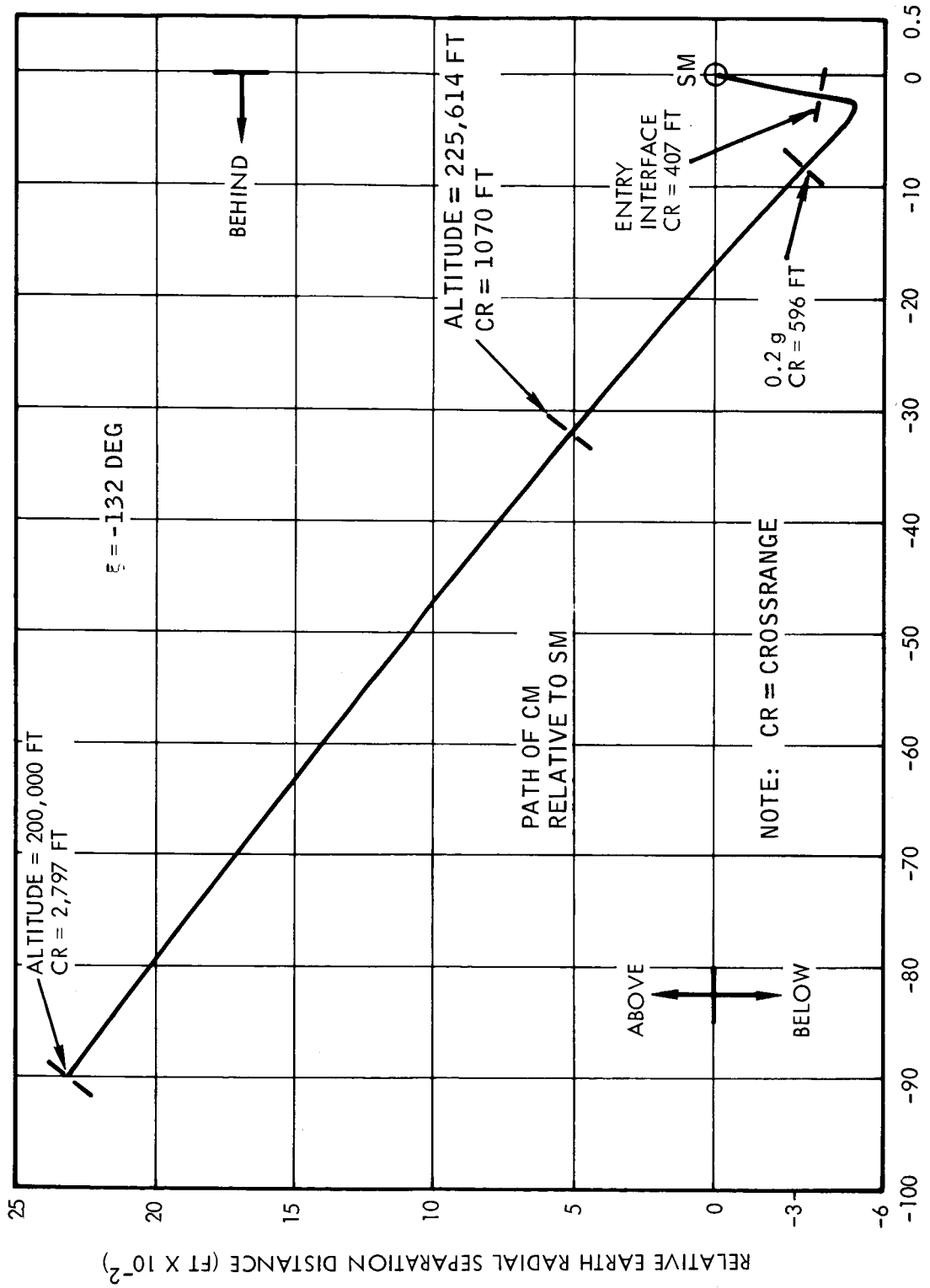Figure 27.- Relative Earth Radial Separation versus Relative Downrange During Entry Following Mode III Abort

Figure 28.- CSM Heads Up Horizon Monitor Attitude

RELATIVE DOWNRANGE SEPARATION DISTANCE (FT X 10^{-2})

Figure 29.- Relative Earth Radial Separation versus Relative Downrange During Entry
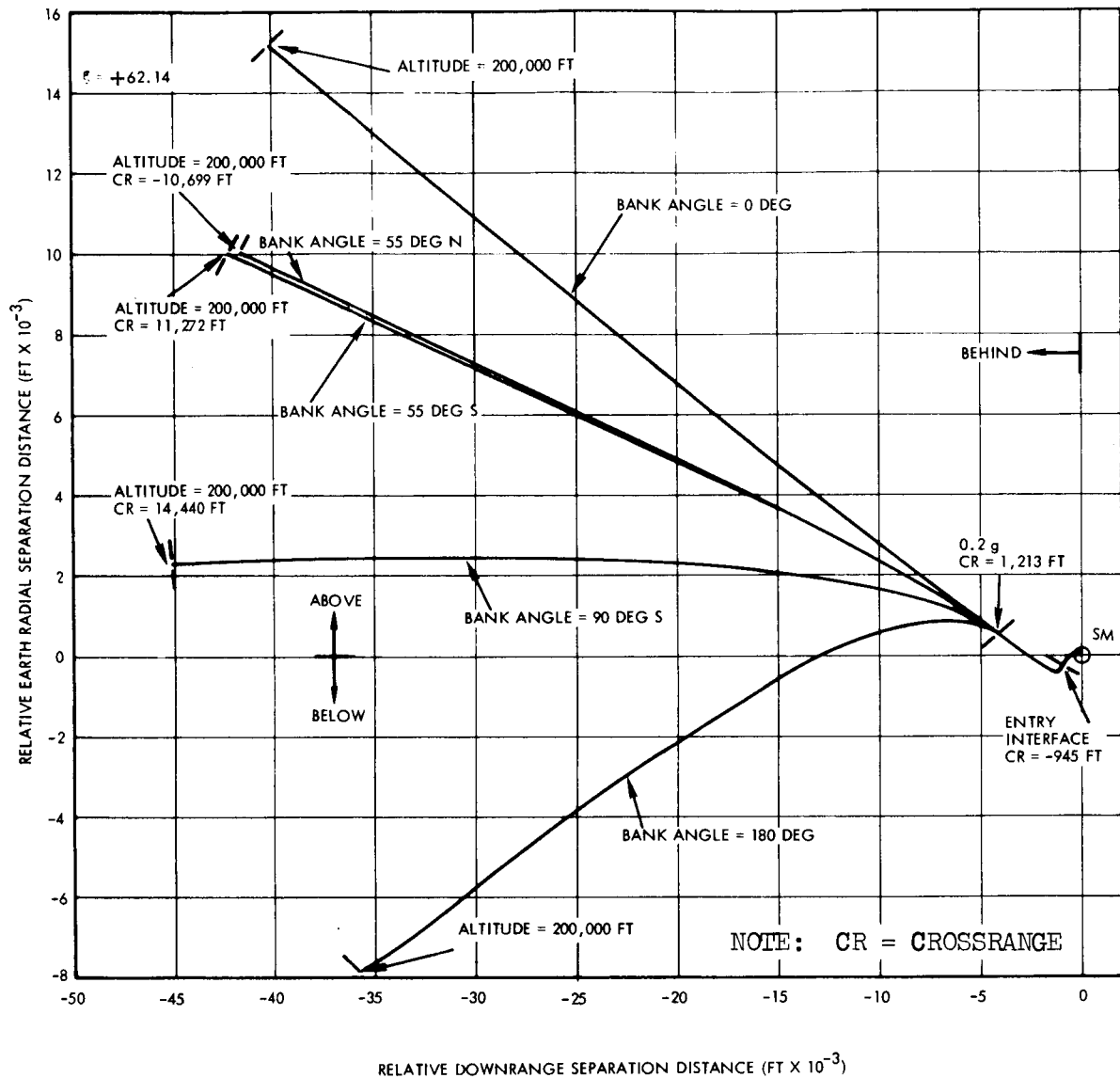
Figure 30.- Relative Earth Radial Separation versus Relative Downrange
During Entry Following EPO Abort

X-BODY AXIS

31.7°

V_i LOCAL HORIZONTAL

LINE-OF-SIGHT
TO HORIZON
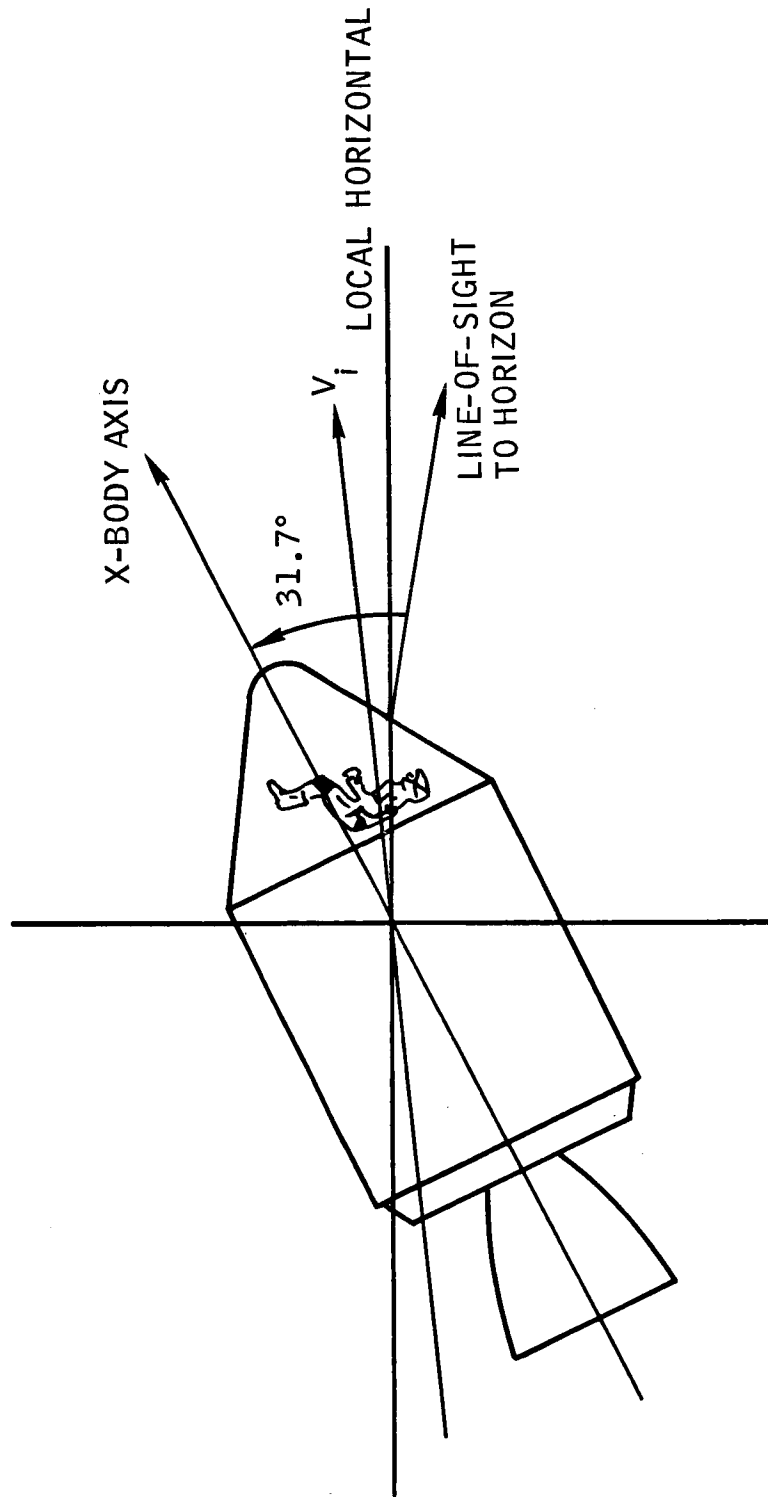
Note: The SCS holds this attitude inertially during
the COI burn

Figure 31.- Mode IV COI attitude, CSM heads down.

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